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A O S T R A

A 15 YEAR PORTFOLIO OF ACHIEVEMENT

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A 15 YEAR PORTFOLIO OF ACHIEVEMENT

15

ALBERTA OIL SANDS TECHNOLOGY
AND RESEARCH AUTHORITY



5	Premier's Message
6	Minister's Message
7	Chairman's Prologue
8	Premiers & Ministers
9	Administration and Management Structure
10	Cumulative Expenditures
11	Authority Members

AN OVERVIEW

14	History and Mandate
16	Principles of Operation
18	Proposal Guidelines
20	Changing Role
22	Future Outlook

RECOVERY

26	In Situ Recovery in the Athabasca Deposit
34	Mining and Extraction
48	Shafts and Tunnels
54	The Cold Lake Deposit
60	The Peace River Deposit
64	The Wabasca Deposit
66	The Grosmont Carbonate
70	Heavy Oils
75	Enhanced Oil Recovery
78	AOSTRA Advanced Oil Recovery Technologies

PETROLEUM PROCESSING

82	Upgrading
86	Commercial Demonstration
90	Improving Residue Utilization

ENVIRONMENT

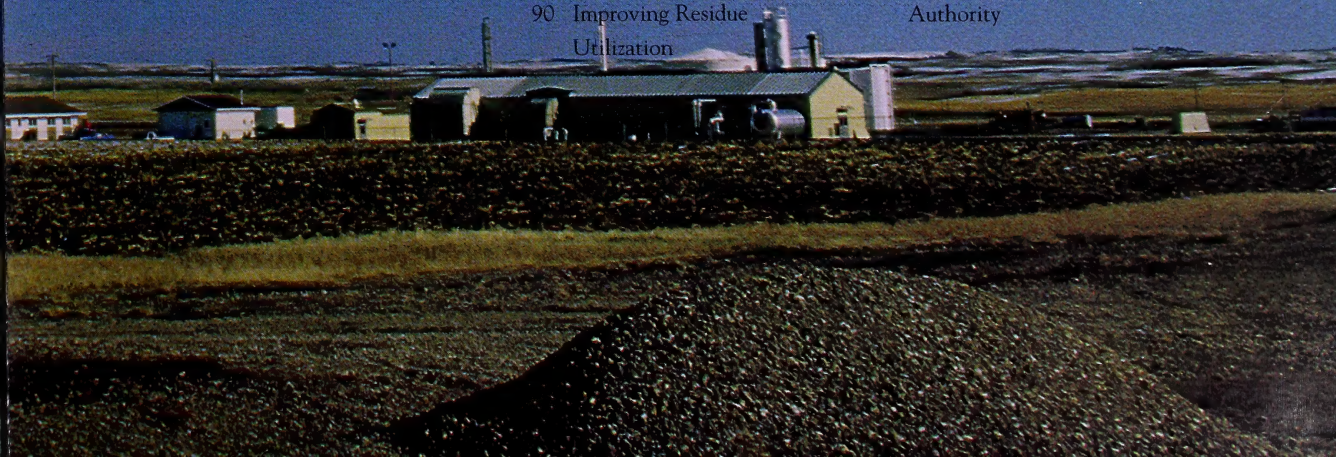
94	Introduction
96	Produced Water Treatment
100	Waste Clean Up
102	Tailings Sludge Studies
104	Air Quality Monitoring
106	Mutagenic Effects
107	Other Concerns

RESEARCH & TECHNOLOGY

110	University Program
130	Alberta Research Council
136	Petroleum Recovery Institute
140	Building Our Technical Workforce
142	Assistance for Inventors
146	Technology Handling
150	Library and Information Services
152	Technical Publications
153	Protecting Intellectual Property
154	AOSTRA Around the World

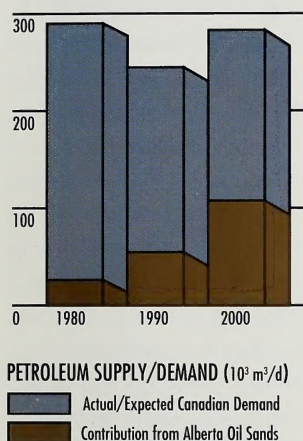
THE ACHIEVERS

160	Karl A. Clark Award
162	AOSTRA People
170	AOSTRA Funding
172	Legal Evolution of the Authority





A SPECIAL MESSAGE FROM
THE HONOURABLE DON R. GETTY
PREMIER OF THE PROVINCE OF ALBERTA:

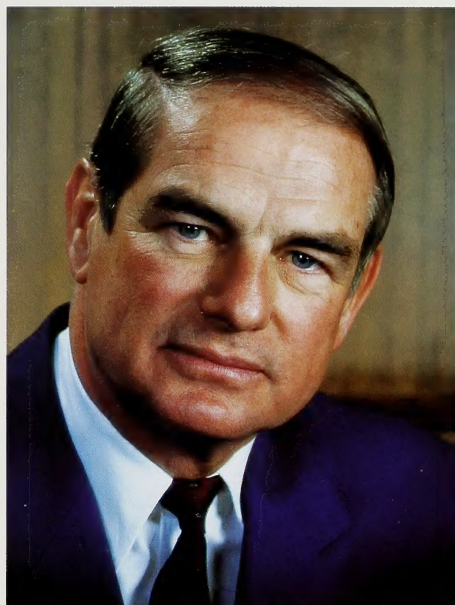


This Portfolio describes achievements of which all Albertans can be justly proud. It is especially close to my heart since I was the Minister of Energy and Natural Resources when AOSTRA first got underway back in 1975.

When it is realized that roughly forty percent of the world's heavy petroleum resources are in our Province, it can be readily understood why the formation of AOSTRA became a top priority of our Government. Furthermore, as the diagram illustrates, an increasing fraction of the Canadian demand for petroleum had to be met by contributions from our oil sands.

I can remember the enormous technical challenges that this young Authority faced in creating the new technology necessary to exploit fully our oil sands and heavy oil resources for the benefit of the people of our Province.

We can now say that these challenges have been met, and with great success, as this Portfolio will attest.



Strong economies, today, are built on a foundation of advancing knowledge, and those who read this Portfolio will see clearly that this Province is forging an economy with the strength, diversity and resilience to provide all Albertans with every opportunity for a truly fulfilling life.

Don R. Getty

Don R. Getty

FROM THE HONOURABLE RICK ORMAN,
MINISTER OF ENERGY AND NATURAL RESOURCES,
THE GOVERNMENT OF ALBERTA:



On the completion of its fifteenth year of operation, The Alberta Oil Sands Technology and Research Authority has prepared this volume entitled "AOSTRA: A 15 Year Portfolio of Achievement," to provide for Albertans, and other interested readers, the exciting story of what has been accomplished in the development of our oil sands and heavy oil resources, and in the enhanced recovery from our conventional oil fields.

And an exciting story of achievement it is, with a constantly recurring theme, and that theme is cooperation. Creating the complex new technologies necessary to exploit fully our vast hydrocarbon resources, in an environmentally acceptable manner, requires the best efforts from many talented and highly-trained people. This Portfolio documents how AOSTRA has been able to develop mechanisms for working together with the private sector, with

the universities and with other government institutions, and indeed, with other agencies throughout the world, in mutually beneficial relations, in the course of achieving its mandate. And here it should be emphasized that AOSTRA has succeeded in bringing about a level of technical cooperation among the various contributing sectors of our society, almost unprecedented in the world today.

This is a volume that should be read and studied not just for the singular technological accomplishments that are described, but for the lessons it teaches on how much can be achieved by a society when people work constructively together toward the realization of a common goal.

A handwritten signature in black ink, appearing to read "Rick Orman". The signature is stylized with a large, sweeping initial "R" and "O".

Rick Orman,
Minister of Energy

*A PROLOGUE BY THE CHAIRMAN,
MR. WILLIAM J. YURKO:*

Alberta is blessed with an enormous treasure of energy in its petroleum resources, but much of this treasure can only become commercially accessible by the combined efforts of many talented and highly creative people. Thus, while Alberta has only about one percent of the world's conventional oil reserves in light and medium crudes; it possesses at least forty percent of the total known global reserves in the heavy petroleums, including the heavy oils and the oil sands bitumens. Most of these heavy petroleum resources are the bitumens locked in our oil sands, and these are geologically estimated to exceed two trillion barrels.

Now, only about 10 percent of the Athabasca oil sands are surface-mineable, and none of the other deposits. This means that 95% of our vast oil sands resources can only be economically developed through totally new technologies. It was to find the ways to create these new, advanced, technologies, in an environmentally acceptable manner, that AOSTRA was formed by our Government in late 1974.

Over the past fifteen years, AOSTRA has become an organization unique in the world as will become obvious to those who read this Portfolio. In achieving its objectives, AOSTRA has worked with some 64 industrial organizations, varying in size from large multi-national petroleum companies to small entrepreneur-driven groups. And in the course of these ventures, the industry and AOSTRA have invested about one billion dollars in these joint undertakings. Two of our joint projects with industry are now fully commercial operations, and several others are approaching that stage, including an innovative, mine-access approach to in situ production.

But AOSTRA's cooperative programs have extended far beyond its industrial efforts. To develop the fundamental concepts for the new technologies, AOSTRA has sponsored programs with research groups in 17 Canadian universities, and some 10 research organizations. In addition, in order to benefit by the mutual exchange of technical information with other research bodies throughout the world, AOSTRA has developed this type



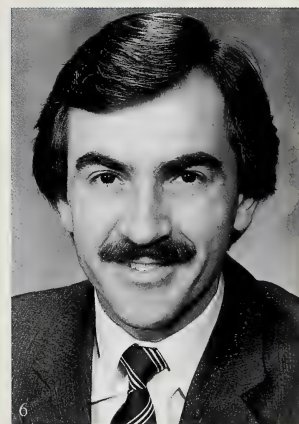
of agreement with 17 countries, covering almost all nations with significant holdings in heavy petroleums. And finally, to assist the individual inventor, who represents an important source of new technical ideas, AOSTRA has created its Inventors Grant Assistance Program.

To date, AOSTRA has entered into 834 agreements with its various partners in new technology development and these have been the vehicles through which the many achievements detailed in this Portfolio have been carried out.

Finally, it is my pleasure, as the current Chairman of this great organization, to acknowledge the many important contributions made by my predecessors, and particularly the founding Chairman, Dr. C.W. Bowman. And in closing, I would like to express a special debt of gratitude to Dr. G.B. Mellon, who has been closely associated with AOSTRA from its very inception.

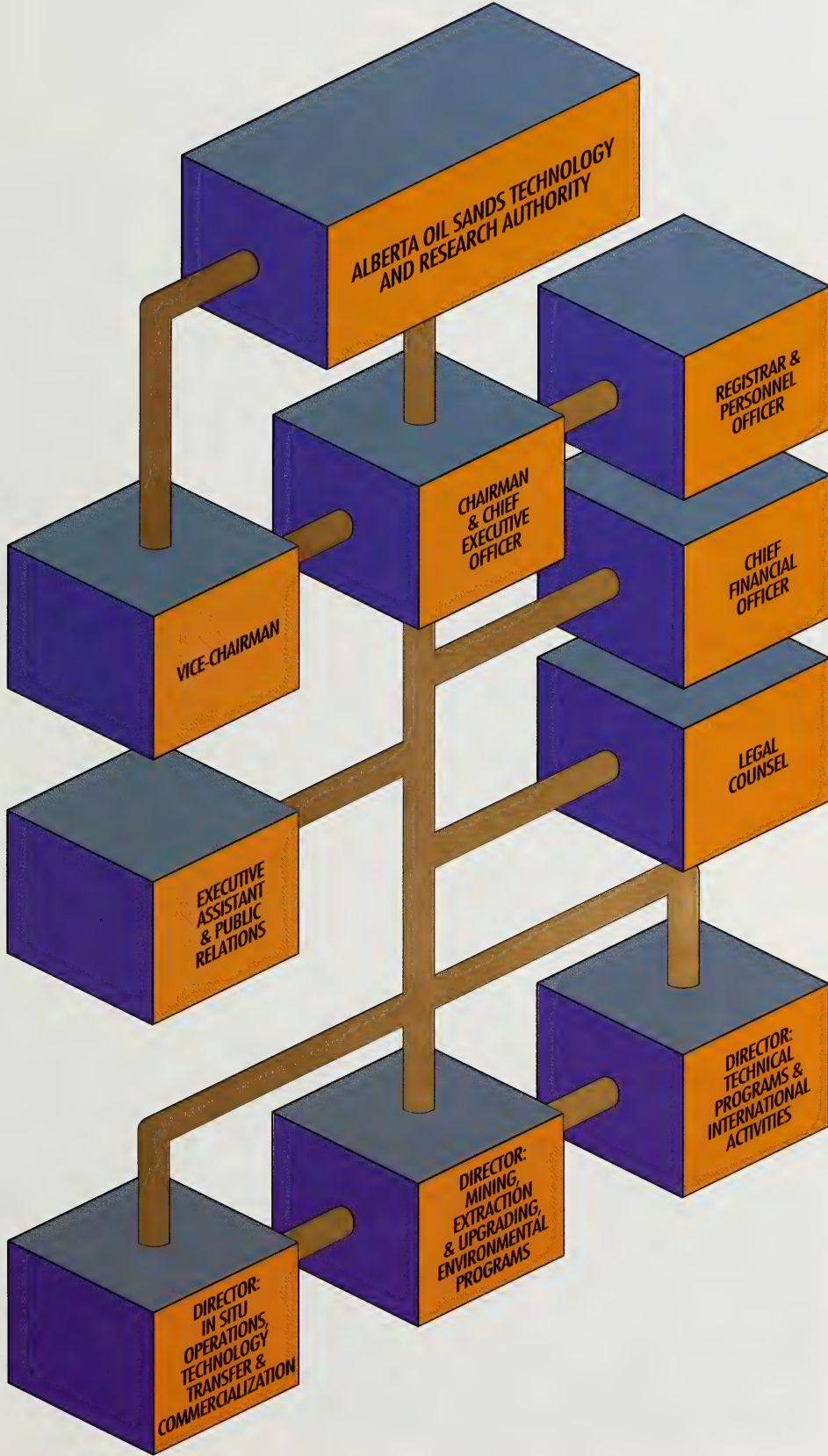
A handwritten signature in dark ink, appearing to read 'W. J. Yurko'.

*William J. Yurko,
Chairman and
Chief Executive Officer*



PAST AND PRESENT PREMIERS
AND ENERGY MINISTERS

- 1 Premier Peter Lougheed, 1971-85
- 2 Premier Don Getty, 1985-Present
- 3 William Dickie, 1971-75
- 4 Don Getty, 1975-79
- 5 Merv Leitch, 1979-82
- 6 John Zaozimy, 1982-86
- 7 Neil Webber, 1986-89
- 8 Rick Orman, 1989-Present



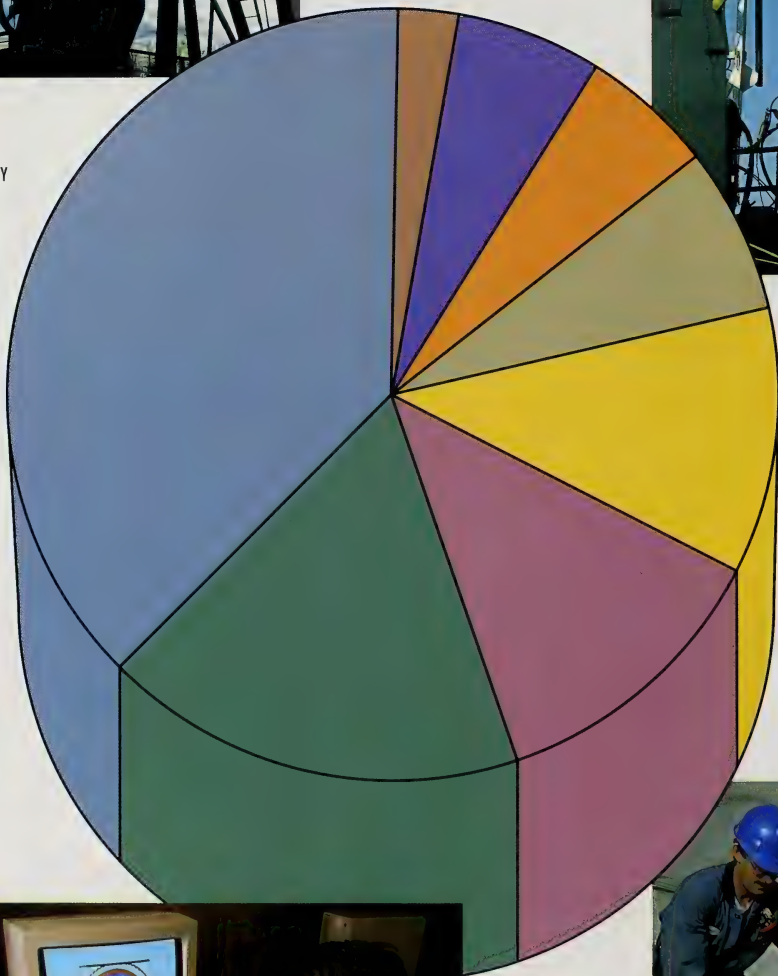
CUMULATIVE EXPENDITURES 1976-90*



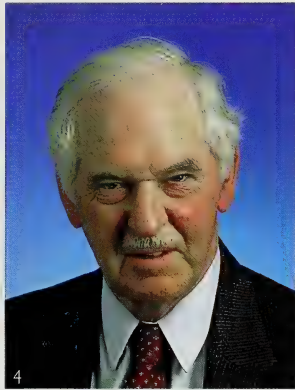
- IN SITU OIL SANDS
- HEAVY OILS AND ENHANCED OIL RECOVERY
- CARBONATE TREND
- UNDERGROUND ACCESS
- MINING, EXTRACTION, UPGRADEING AND ENVIRONMENTAL
- INSTITUTIONAL PROGRAMS
- TECHNOLOGY TRANSFER, TRAINING, INTERNATIONAL PROGRAMS AND AUTHORITY COSTS
- ADMINISTRATION

TOTAL EXPENDITURES:
\$571.9 MILLION

* FIGURES FOR 1990 BASED ON ESTIMATIONS



AUTHORITY MEMBERS



- 1 William J. Yurko,
Chairman
- 2 R.S. (Dick) Aberg
- 3 Ray M. Allison
- 4 Fred A. Kidd
- 5 J.E. (Bud) Miller
- 6 Joseph M. Richardson
- 7 Ernest J. Wiggins
- 8 Gordon R. Shrake

- A C.W. Bowman (Founding
Chairman), 1975-1984
- B M.A. Carrigy, 1975-1987
- C H.E. Gunning, 1979-1987
- D J.A. Harvie, 1979-87
- E M.G. Pahl, 1981-82
- F K. Paproski, 1980-81
- G N.A. Weiss, 1979-80
- H S.P. Zarusky, 1988-89

AUTHORITY MEMBERS 1975-79

Front, l to r: E.E. Ballantyne, 1975-78, P.E. Gishler, 1975-79, M.A. Carrigy, 1975-87, E.P. Johnson, 1975-76.

Back: E.J. Wiggins, 1977-Present, R.D. Humphreys, 1976-79 and 1984-86, C.W. Bowman, 1975-84, F.A. Kidd, 1975-Present, F.K. Spragins, 1977-78



A N O V E R V I E W



THE ALBERTA OIL SANDS TECHNOLOGY AND RESEARCH AUTHORITY IS A CROWN CORPORATION ESTABLISHED BY AN ACT OF THE LEGISLATIVE ASSEMBLY IN JUNE 1974. THE ACT ORIGINALLY LIMITED AOSTRA'S ACTIVITIES TO OIL SANDS, BUT WAS AMENDED IN 1975 TO INCLUDE HEAVY CRUDE OIL AND WAS AMENDED AGAIN IN 1979 TO EXTEND ITS ACTIVITIES TO THE ENHANCED RECOVERY OF CONVENTIONAL CRUDE OIL.



Along with oil, water, sand, and gas are produced. This vessel is used to separate these materials and clean the oil.

The considerations which led to the Alberta Government's decision to establish AOSTRA were the recognition that the Alberta oil sands would have to play a large and increasing role in maintaining the province's position as the leading producer of liquid fuels in Canada as conventional reserves declined, and that 95% of the potentially recoverable reserves of oil sands bitumen would have to be produced by methods other than surface mining. The necessity of developing new methods for exploiting most of the resource, and the very long lead times involved in eventual commercial development, suggested that government could play a vital role by planning for the long term with a broader perspective than the private sector could be expected to bring to bear.

A review of the roles and capabilities of existing government agencies indicated that it would be advantageous to establish a separate body with the sole purpose of funding and coordinating technology development and dissemination in this specific field. It was hoped that industry and government would work together to ensure an orderly progression from research through the pilot stage to commercial ventures.

In speaking to the proposed legislation, the Honorable W. D. Dickie, then Minister of Mines and Minerals, stated that AOSTRA's role would be to coordinate and interact with industry, and the manner and extent of that interaction was entirely dependent on the reaction of the industry and its willingness to share proprietary data in order to provide a base from which to generate new technology. He hoped that AOSTRA would serve as a completely independent vehicle into which such technology could be funnelled to prevent an overlapping of research activities.

The AOSTRA mandate, as embodied in the original Act and amendments, can be briefly stated as follows:

- to promote research and development into the technological methods required for the efficient and economic recovery and processing of crude

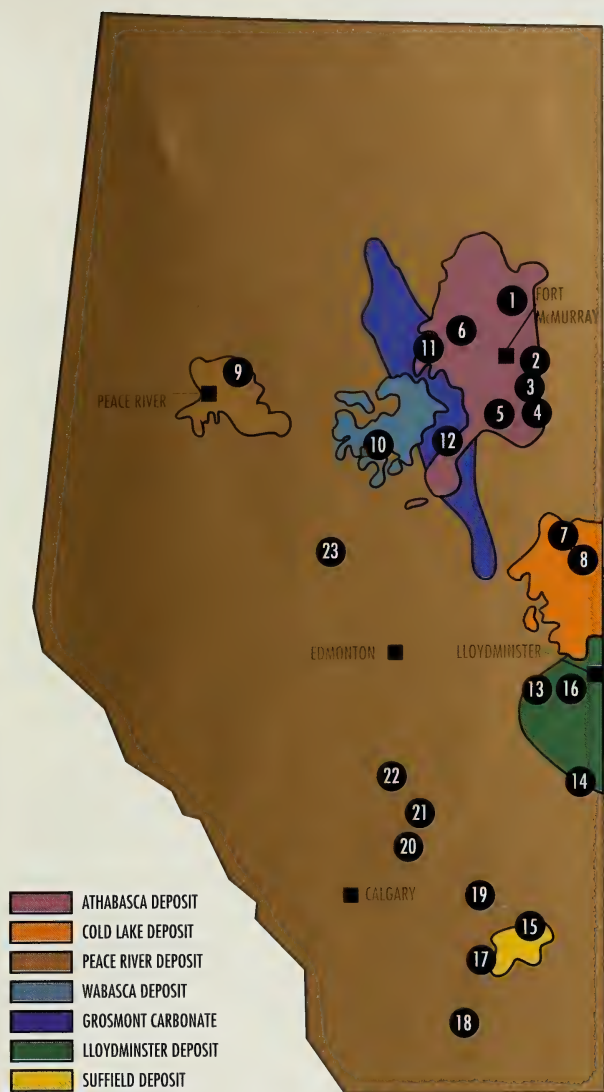
bitumen and other oil sands products from the oil sands deposits, and the effective and economic recovery of crude oil through the use of enhanced recovery methods;

- to promote research into the technological methods required to ensure an acceptable quality of the environment during and after such recovery and processing operations;

- to promote and implement solutions to technological problems impeding the development of production capacity to meet the demand for crude oil, synthetic crude oil, and products derived from crude oil.

Other important missions assigned to AOSTRA were the compilation, assessment, and dissemination of technological information relating to oil sands, heavy oil, and enhanced recovery of conventional oil, and the promotion of cooperation among the Government of Alberta, industry, universities, and other institutions or agencies in these fields.

AOSTRA's operations were initiated by the allocation of \$100 million from the Alberta Heritage Savings Trust Fund for the first five-year program, and by the appointment in 1975 of seven members to the Authority. All of these Members were professional engineers or scientists with



previous direct technical experience with the Alberta oil sands, combined with considerable management experience. During the Authority's first year of activity, a number of steps were taken which have, to a large extent, shaped its operations to the present day. The Members identified two specific goals for the Authority:

- to increase the pace of research, which previously had been intermittent or short term in nature;
- to ensure the use in Alberta of the most advanced technology available.

A series of discussions were held with the petroleum industry and with professional organizations such as the CPA, IPAC, APEGGA, and the CIM which led to the definition of the six most important objectives of the Authority, as follows:

1. At least one in situ recovery process for each major oil sand reservoir type.
2. More effective, efficient, and environmentally acceptable upgrading technology.
3. Resolution of major technical problems of current surface mining technology.

AOIRA/INDUSTRY PILOT PROJECTS

1 HUSKY	13 PETRO-CANADA
2 TEXACO	14 NORCEN
3 AMOCO	15 AEC
4 NUMAC/GULF	16 HUSKY
5 PCEJ	17 PANCANADIAN
6 AOIRA UTF	18 ULSTER
7 BP	19 AMOCO
8 BOW VALLEY	20 BUMPER
9 SHELL	21 GULF
10 GENERAL AMERICAN	22 VIKOR
11 UNOCAL	23 CANADIAN HUNTER
12 CHEVRON	

4. Evolutionary increases in percentage recovery from in situ processes.

5. Alternative surface extraction technology.

6. Conversion of oil sands and heavy oils into higher-valued petroleum and mineral products.

Several important policy decisions were also made during the first year:

■ AOIRA would not construct any research facilities of its own, but would make use of existing facilities. When needed, the Alberta Research Council would act as the Authority's technical arm, but would not receive preferential treatment in the award of research contracts.

■ All promising research concepts would be considered regardless of source, and when appropriate, the early stages of the work could be carried out at any geographic location.

However, once an ongoing program was identified, every reasonable effort would be made to bring the research activities to Alberta.

■ When engaging the services of consultants and contractors, the Authority would seek Alberta services first, Canadian second, and non-Canadian third. It was recognized that an Alberta base of private-sector expertise could only be developed through direct involvement in oil sands technology.

■ The Authority would accumulate, retain, and make available oil sands technology on a commercial basis, so that the best technology would be available to all who could benefit from it, at reasonable rates, bearing in mind the best interests of Albertans.

Over the following few years, a more complete set of principles were developed by the Authority for the ownership, use, disclosure and licensing of technology, and for license fee sharing. Principles were also established for assisting inventors in the development of unproven inventions, for testing commercially available processes or equipment for oil sands applications, for handling of university projects, and for international cooperative agreements. These principles are outlined in the next section.

AOSTRA IS COMMITTED TO EVALUATING ALL PROPOSALS FOR RESEARCH AND DEVELOPMENT THAT FALL WITHIN ITS MANDATE ON A FAIR AND EQUITABLE BASIS, REGARDLESS OF ORIGIN.



Proposals must be made in the form of a written application, although applicants may also, on request, make a personal presentation at a regular Authority meeting. The selection of applications for funding is made by the Authority on the basis of recommendations from an internal committee, supplemented by external evaluations if needed, and taking into account AOSTRA's overall priorities and availability of funds. All approved projects are implemented through formal agreements with the company or institution.

The largest class of research and development activity funded by AOSTRA is the field pilot testing of in situ production, mining, and extraction

technology. These projects are normally carried out on a 50:50 funding basis between AOSTRA and a company or group of companies, with one of the companies as operator, on the operator's lease. Such projects are conducted under agreements based on the principles summarized in Section A on page 18.

A key consideration in developing these principles was to strike an appropriate balance between protection of proprietary interests and right of access to information generated with public funds. Technology ownership was vital to AOSTRA so that it could be made available to any legitimate user, but protection of industry's proprietary information was also essential if they were to bring their best concepts to AOSTRA for joint development.

While the preceding is regarded as the standard form of AOSTRA-industry technology development agreement, there may be substantial variations in cases where AOSTRA takes a minority interest, or where the company has a fully-developed technology which mainly requires adaptation to oil sands applications. An important example of the latter situation is the demonstration of the performance of a new upgrading process with oil sands bitumen by feedstock tests in company-owned facilities. In this

case ownership of the process remains with the company, and AOSTRA technology ownership is essentially limited to the test results.

One program in which AOSTRA takes no ownership position is the Inventors Grant Assistance Program summarized in Section E. This program is designed to assist individual inventors in developing an invention to the stage where conventional financing may be obtained for commercialization, and for obtaining patent protection. The only requirement from the inventor is the provision of acceptable technical and financial reports to ensure that the funds are used only for the development of the invention. Financial support under this program is limited to \$50,000 for any one invention.

In the AOSTRA University Program summarized in Section D, the researchers are encouraged to publish their results through normal channels, but must first submit manuscripts of proposed publications to AOSTRA for identification of potentially patentable material so that any necessary patent action can be taken. Ownership of patents arising from the University Program is assigned to AOSTRA. The main avenue for technology transfer to industry is the Access Program, which pro-

vides member companies with ongoing research reports, opportunities to interact with the researchers, and in the case of full membership, use rights to the technology.

The operating principles adopted for these programs have successfully withstood the test of time with only minor modifications. AO STRA's requirement for technology ownership was an understandable source of concern for many companies at first, but the concept of licensing technology to third parties at fair market value, or, as sometimes expressed, "technology freely available but not for free" has proven to be an acceptable compromise for most companies.

The growing realization that most new oil sands projects will require the participation of several companies, often with some type of government involvement, has also tended to reduce sensitivity over the competitive advantage of individual companies in recent years.

The Inventors Grant Assistance Program has proven highly popular, and has led to several commercially-promising developments. The University Program originally aroused some of the normal concerns over the imposition of added requirements and restrictions on the researchers. However, the faculty members who have become involved in

the program have generally found such interference to be minimal and to be more than made up by the opportunity of interacting with industry researchers in allied fields. This program represents one of the most successful examples of university-industry-government collaboration in Canada.

Catalysts make things go faster. These catalysts speed up selectively the chemical reactions used to refine bitumen, thereby improving productivity.



A. TECHNOLOGY OWNERSHIP AND USE RIGHTS IN AOSTRA/INDUSTRY AGREEMENTS

■ AOSTRA generally contributes 50% of project funding and has 50% of management control.

■ AOSTRA generally owns all new technology, keeps this technology confidential, and obtains patents.

■ AOSTRA is the exclusive licensor for new technology in Canada.

■ AOSTRA, in distributing the licensing income, may include a company's prior technology as required to complete its licensing package, with recognition of that company's expenditures for the prior technology.

■ AOSTRA, Alberta Government agencies and their affiliates, and the industrial parties to the agreement and their affiliates, may use project technology without payment of licensing fees; all others pay a license fee.

■ AOSTRA may place a technical representative in the company's office at project expense to acquire technology and assemble it in the form necessary for licensing.

■ AOSTRA and the company generally own all the project's physical assets on a joint basis and share all revenues from their disposition and proceeds from the sale of products.

■ AOSTRA generally requires repayment of its investment in a project from commercial operations on a time value of money basis.

■ AOSTRA and the company can jointly or individually license outside Canada.

■ Regardless of who grants a license, licensing income is shared in proportion to financial contribution.

■ AOSTRA licenses third parties at a fair market value fee established by agreement with the participating company, or failing that, by arbitration.

B. INTERNATIONAL COOPERATIVE AGREEMENTS

■ AOSTRA is willing to carry out a select set of analyses, at no cost, on samples submitted to it by another country. These analyses will assist AOSTRA and that

country in preparing a resource development plan.

■ AOSTRA will enter into international agreements for data exchange, personnel exchange, and for joint projects. Examples are as follows:

(a) A jointly financed project in which exclusive use and licensing rights to inventions would be granted to each party in its own country, and with shared or symmetrical licensing rights in other countries.

(b) The costs for exchange of scientists would normally be:

- i. sending country pays salary and travelling costs to the host country;
- ii. host country pays living and all employment expenses.

RIGHT: By using X-rays and high speed computers, we can now measure the amount of oil and water flowing through each cubic millimetre of the large volume of sand contained in this vessel. These techniques are vitally important in determining the effects of new processes on oil recovery.



Professor Qi-Yuen Chen, visiting from The People's Republic of China is developing a device for recovering valuable hydrogen and sulphur from hydrogen sulphide gas.





■ AOSTRA will seek opportunities to market its own technology in other countries, as required in our joint project agreements. AOSTRA will attempt to use Albertan and Canadian companies in the implementation of such technology; for example, in detailed design, procurement, and construction activities.

C. TESTING COMMERCIALLY AVAILABLE PROCESSES OR EQUIPMENT FOR OIL SANDS APPLICATIONS

In the case where there is economic uncertainty involved in the use of existing processes or equipment which have not

previously been tested for oil sands application, AOSTRA may decide to fund a demonstration test. The proprietary rights will normally be owned by other parties. In lieu of obtaining a share in such proprietary rights, AOSTRA would attempt to recover its investment on a time value of money basis by one or more of the following mechanisms:

- sale of data by AOSTRA to industry;
- share of licensing revenue;
- share of revenue from manufacturing equipment;
- share of product revenue from commercial application.

The multiple of three was selected to reflect both the risk involved and the time value of money.

D. HANDLING OF UNIVERSITY PROJECTS

■ Applications will be accepted from all Canadian universities and will be reviewed by a panel comprised of experienced researchers.

■ The panel will present its recommendations to the Authority Members no less frequently than semi-annually.

■ Approved projects will be carried out under the direction of the principal university researcher, with technical support from the Authority as is deemed appropriate.

■ AOSTRA will promote the involvement of industry as "Consultive Participants." Each such participant will pay a specified percentage of the cost of the project and will obtain full use rights to the technology developed.

■ AOSTRA will own patents developed in the projects. An honorarium will be paid to the inventor on filing, and when the patent application is granted.

■ AOSTRA will, not less than annually, review the following subjects:

- (a) priorities for university research;
- (b) progress and results of university projects.

Furthermore, AOSTRA will seek and employ such expert advice as required to effectively conduct such reviews.

E. INVENTORS GRANT ASSISTANCE PROGRAM

■ AOSTRA will recognize the proprietary position of the inventor and will not own the new technology.

■ Financial assistance is limited to \$50,000 for any one invention.

■ AOSTRA funds must be used to complete the development of an invention or to obtain patent protection.

■ Technical and financial reports must be provided to AOSTRA on completion of the project.

AS NOTED EARLIER, THE BROAD OBJECTIVES AND OPERATING POLICIES ADOPTED BY AOSTRA HAVE PROVEN REMARKABLY RESILIENT TO THE CHANGING CIRCUMSTANCES OF THE PAST 15 YEARS. HOWEVER, THERE HAVE BEEN SIGNIFICANT EVOLUTIONARY CHANGES IN SEVERAL AREAS.

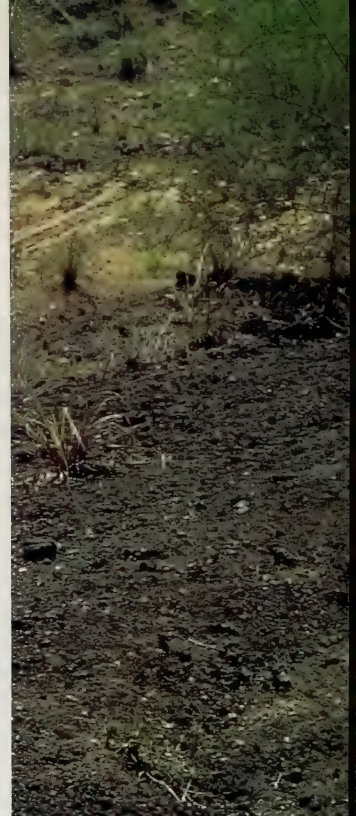


One of these arises from the progressive growth of AOSTRA's in-house technology base. When AOSTRA commenced operations it necessarily relied almost entirely on industry for new concepts and for the formulation of detailed proposals for field pilot tests. Selection of proposals for funding was made with extensive assistance from private consultants. On completion of a project, the analysis and interpretation of results and any recommendations for further work were again made by the industry partner.

However, over the past 15 years AOSTRA has participated in pilot projects in all of the major oil sands and heavy oil deposits of Alberta, using a wide variety of production techniques. As a result it has now accumulated a bank of performance data and operating experience which is considerably greater than that of any one company. It is now able to identify required areas of research and promising new approaches through analysis of the results of a number of field projects. In the mining, extraction, and bitumen upgrading areas, AOSTRA has similarly

participated in pilot and demonstration tests with a considerable range of technologies, and has accumulated a large bank of performance and cost information. In consequence, AOSTRA is now able to shift from an essentially reactive role to one of designing and initiating new projects.

The changed economic and market situation is also leading to evolutionary changes in AOSTRA's mode of operation. In the earlier years, with the expectation of oil shortages and increasing prices, AOSTRA's industry partners were primarily concerned with the solution of production problems. They expected to use any successful technology in their own projects, and their financial situation was generally such that they were able to justify 50% financial participation in any project of sufficiently direct interest. In recent years, with unstable oil prices and no immediate supply shortage, industry has understandably become much more conservative in undertaking major research and development projects. Consequently, AOSTRA is finding it necessary to provide more than 50% of the cost in certain cases, particularly in the earlier phases where the emphasis is on development of new technology rather than on pre-commercial activities.



As a result both of AOSTRA's stronger technology position and of industry's more cautious attitude, AOSTRA is now taking the initiative more frequently in enlisting industry participation in joint projects. It is still AOSTRA policy to have an industry partner as project operator whenever possible. However, in one major instance the technology to be investigated was so unfamiliar to the conventional oil industry that no company was prepared to assume a share of the considerable front-end investment that was required before the concept could be tested. This project involved the drilling of horizontal wells from mine tunnels in the Athabasca deposit for steam injection and gravity drainage, and it was necessary for AOSTRA to construct the facility and operate it for a sufficient period to demonstrate its technical



Brian Rottenfusser assists a Cuban geologist to examine an oil-sandstone outcrop for the potential application of Alberta's commercial recovery technology.

feasibility before industry was prepared to join the project. Industry participation is now at a very encouraging level, and it is expected that it will eventually be possible to turn the project over completely to industry for commercial operations.

Another area of evolutionary change is in the relative priorities given to various activities, as exemplified by the increasing attention currently being given to environmental projects in response to the high level of concern by the Government and general public. Environmental considerations have always been important driving factors in such AOSTRA projects as alternative extraction processes for mined oil sands and the treatment of produced water for re-use in steam generation for in situ operations. However, environ-

mental benefits have more often been a subsidiary aspect of a project designed to increase production or reduce costs. In the past few years AOSTRA has been giving increased emphasis to the minimization of environmental impact as a primary objective, as in the use of the AOSTRA Taciuk Processor for waste treatment, and in initiating new projects specifically with this objective.

Another area of significantly increased activity in recent years is technology transfer and commercialization. This has been made possible by the growing inventory of marketable technology, representing an investment of the order of \$1 billion by AOSTRA and its industry partners. There is also a strong desire to use this technology as an avenue of increased economic activity in Alberta. AOSTRA now has a

fully operative Technology Transfer and Commercialization office to provide access to AOSTRA-owned technology and programs, and is entering into an increasing number of technology transfer agreements.

AOSTRA's international activities have also been strengthened considerably over the past few years. Almost from its inception, AOSTRA has promoted technology transfer and exchanges of personnel with other countries with interests in oil sands and heavy oil. It was a founding member of the UNITAR/UNDP Information Center for Heavy Crude and Tar Sands, and has hosted both the first and fourth UNITAR/UNDP International Conferences on Heavy Crude and Tar Sands in Edmonton in 1979 and 1988, respectively. These activities have helped to establish AOSTRA as a world centre of information and

technology for non-conventional oil development, and have led to many requests for assistance. In cooperation with other Alberta departments and agencies, AOSTRA's international contacts facilitate access by Alberta consultants, equipment manufacturers, and service companies to markets in these countries, many of whom prefer to establish initial contacts with government agencies rather than the private sector.

Because of their importance in bringing increased economic activity to Alberta, strong efforts are being made to increase the number of technology cooperation and exchange agreements with other countries in all aspects of oil, natural gas, and oil shale development.

AOSTRA AND ITS INDUSTRIAL PARTNERS, TOGETHER WITH THE INDEPENDENT EFFORTS OF THE PRIVATE SECTOR, HAVE NOW DEVELOPED TECHNOLOGY FOR EXPLOITING MUCH OF THE OIL SANDS AND HEAVY OIL RESOURCES OF ALBERTA. IN ESSENCE, THE FIRST OF AOSTRA'S ORIGINAL "SIX MOST IMPORTANT OBJECTIVES" HAS ALREADY BEEN REACHED.

Further research will always be required to reduce costs, improve resource recovery, and extend recovery technology to more difficult parts of the deposits. However, a major objective of AOSTRA in the future will be to encourage the commercial utilization



This field pilot near Bodo, Alberta is operated by Norcen Energy. The building in the foreground contains the powerful computers for monitoring the instruments that measure the progress of the novel in situ combustion process being tested here.

of the technology that has already been developed to the pilot stage, by organizing demonstration projects and, where appropriate, by taking an equity position in pre-commercial projects. Cost recovery from eventual commercial operations will form a part of

AOSTRA's participation in such projects. However, it is not expected that AOSTRA will become a direct participant in commercial projects, but will turn over its interests to an industry operator as soon as commercialization is assured.

High priority will be given to the solution of any environmental problems that may hinder large scale oil sands development, so that synthetic crude can fill its expected role in North American liquid fuel supplies. These efforts will include minimization of carbon dioxide emissions during production and processing, in line with current concerns over global climate warming. Increased emphasis will also be given to maximizing the value added during bitumen processing both by increasing the liquid yields and product quality, and also through conversion to chemicals and other non-fuel products. As further measures toward obtaining the best economic returns from AOSTRA's activities, both the International and the Technology Transfer and Commercialization Programs will continue to be strengthened.

Despite the emphasis on programs of immediate economic benefit, every effort will be made to maintain the University, the Alberta Research Council, and other institutional programs at their present



In the field pilots, commercial-size equipment is tested, wherever possible, as in this photo.

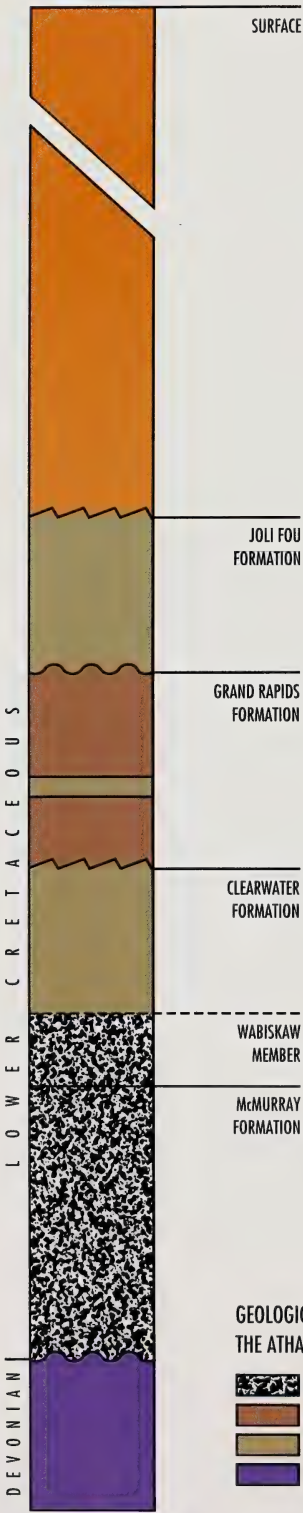
or enhanced levels, preferably with increased industry participation. These programs represent an essential investment in maintaining the flow of new concepts and technology which will provide the foundation for future pilot and commercial projects. One of AOSTRA's strengths has been the fact that its activities have spanned the spectrum from research through laboratory pilots to field pilots, and most recently to demonstration and pre-commercial projects. Continuation of this policy will ensure that Alberta remains a world centre of non-conventional oil development.





RECOVERY





THE ATHABASCA OIL SANDS DEPOSIT, LOCATED IN NORTHEASTERN ALBERTA IS THE LARGEST OF ALBERTA'S OIL SANDS DEPOSITS AND IS ONE OF THE WORLD'S LARGEST AND BEST KNOWN RESOURCES OF BITUMEN.



Outcroppings of the oil sands, pictured below, can be seen along the Athabasca river valley. Only about 10% of the deposit may be recovered using surface mining methods, shown at right. The remainder which are deeply buried will need to be recovered by in situ production methods.



The deposit covers some 46,800 square kilometres and contains approximately 151 billion cubic metres (950 billion barrels) of bitumen. By comparison this resource is 17.5 times larger than what is currently estimated to be the remaining, technically recoverable, conventional oil in Canada.

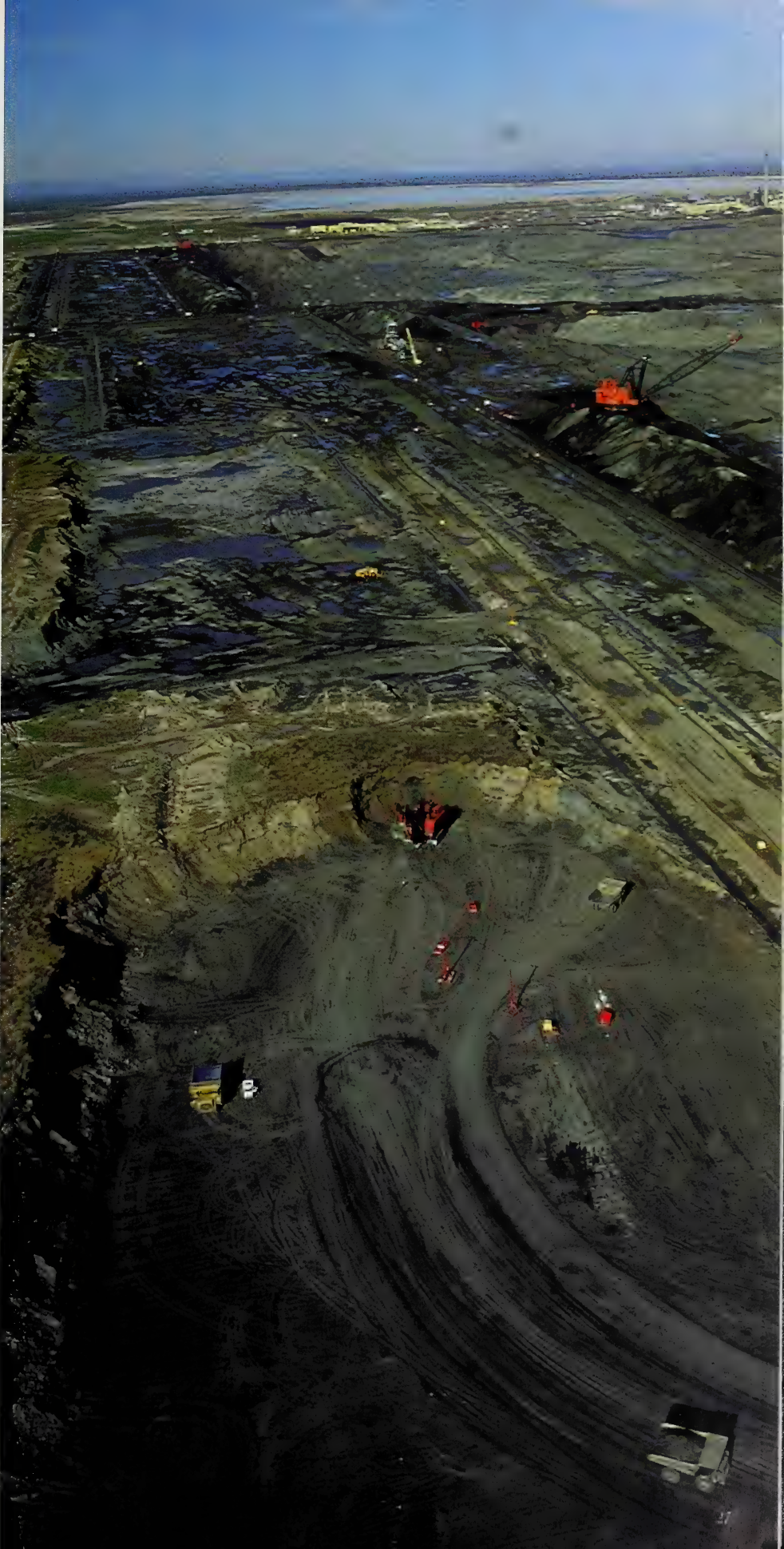
In those areas where the sand is covered by less than 45 m of overburden, which represents roughly 10% of the deposit, the oil sand can be surface mined. The well-known Suncor and Syncrude operations, which are located on the Athabasca River approximately 30 km north of Fort McMurray, exemplify this type of recovery by mining.

The Athabasca bitumen is to be found primarily in the McMurray, Lower Cretaceous, sand formation. These sands have an average thickness of 38 m. Outcroppings can be seen along the Athabasca and Clearwater river valleys where the rivers have eroded into the oil sands. In the southwest the deposit reaches depths of up to 750 m.

The bitumen from oil sands lying deeper than 45 m is currently considered uneconomical for recovery by surface mining and therefore it must be removed from the sand by in situ recovery techniques.

Over the years, a wide variety of in situ recovery methods have been investigated, starting with the first steam test by the bituminous Sand Extraction Co. Limited in 1926. By 1930, J.O. Absher, the principal engineer for the company, wrote to his shareholders, "I feel that we have overcome the technical difficulties and are able to produce on a commercial basis." In the sixty years since that time and despite numerous subsequent attempts, the Athabasca in situ deposit still remains a formidable challenge.

The challenge arises primarily from the complex geology of the McMurray formation together with the very viscous, non-flowing nature of the bitumen which makes its recovery very difficult indeed. However, the immense size of the resource dictates that the formidable problems associated with recovering the in situ bitumen in the Athabasca formation must be solved. It was primarily this challenge which led to the creation of AOSTRA in 1974. At that time, five important pilot tests had been completed in the in situ sands and two were in operation.



Shell Canada Resources Ltd., during the period 1957 to 1962, attempted to recover bitumen from a shallow Athabasca oil sands deposit at their Muskeg River Pilot. The test consisted of hydraulic fracturing near the base of the deposit using caustic solution, followed by steam from the injection wells. Production wells were stimulated with a hot caustic solution to emulsify the bitumen. Communication between the wells was achieved and encouraging amounts of bitumen were produced. However, declines in production were encountered, requiring repeated production well stimulations, with hot caustic and steam, to maintain the output of bitumen, which adversely affected the economics of the operation.

From 1957 to 1976 Amoco Canada Petroleum Company Ltd. conducted tests at Gregoire Lake in the Athabasca. Various forms of combustion were tried culminating in the development of the COFCAW process (a combination of forward combustion and water). This process was first tested in a small five-spot pattern, which confirmed the potential for the process. Following this successful COFCAW experiment, field trials to define reservoir control methods and well completion techniques were carried out right up to 1976. These Gregoire Lake operations led to a demonstration pilot at Block I in which AOOSTRA participated.

At their Pony Creek Pilot, Atlantic Richfield tested the recovery of bitumen from the deeply buried Athabasca



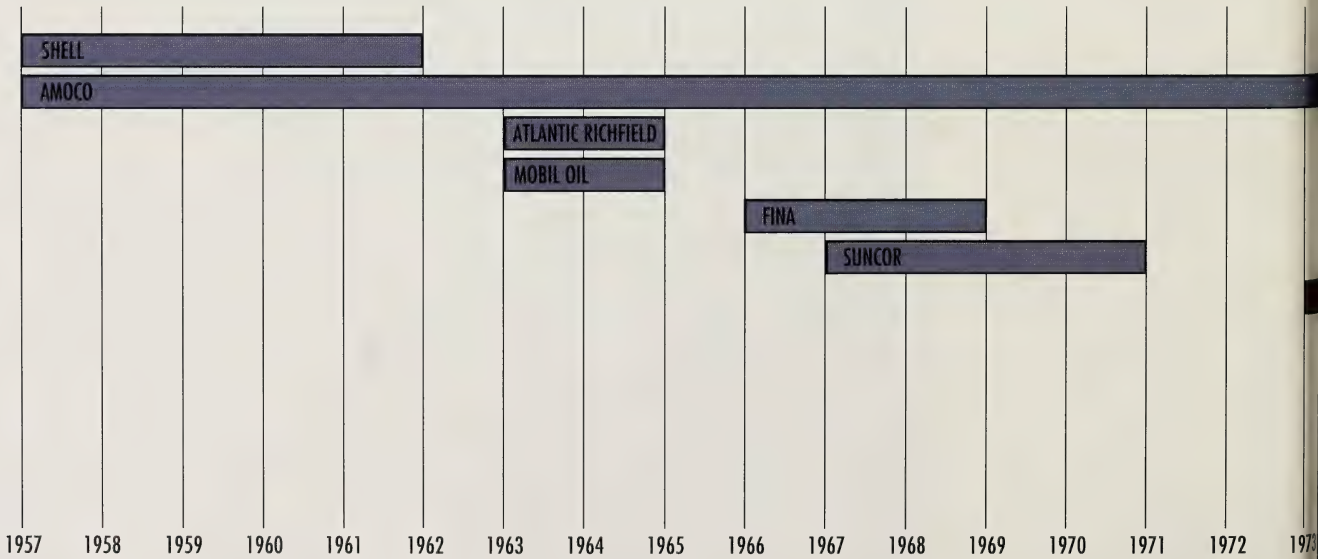
Aerial view of the Amoco/AOOSTRA Gregoire Lake Block I pilot project.

deposits over the period 1963 to 1965. The objective was to establish horizontal fractures between injectors and producers and operate a steam drive. Unfortunately the fractures appeared to be vertical with very limited connections to neighbouring wells. Since communication between wells was not achieved, the site was used to study steam stimulation. But, again this was unsuccessful due to very limited production yields.

In this same 1963 to 1965 period, Mobil Oil Canada conducted an inverted nine-spot combustion test in a propped horizontal fracture. Well damage from the hot operating conditions and corrosion problems in the surface facilities were encountered, leading to the termination of the project.

From 1966 to 1969, Fina Oil Company sought to recover bitumen from a shallow

IN SITU PROJECTS IN THE ATHABASCA DEPOSIT





Athabasca deposit at their Steepbank Pilot. The recovery concept envisioned was to establish communication between wells by hydraulic fracturing. These fractures could then be converted into hot communications paths, leading to bitumen recovery by steam drive. In the initial five-spot pattern, primary communication achieved between wells, was later lost as the injection and production wells became heated. In the second five-spot pattern, better success was

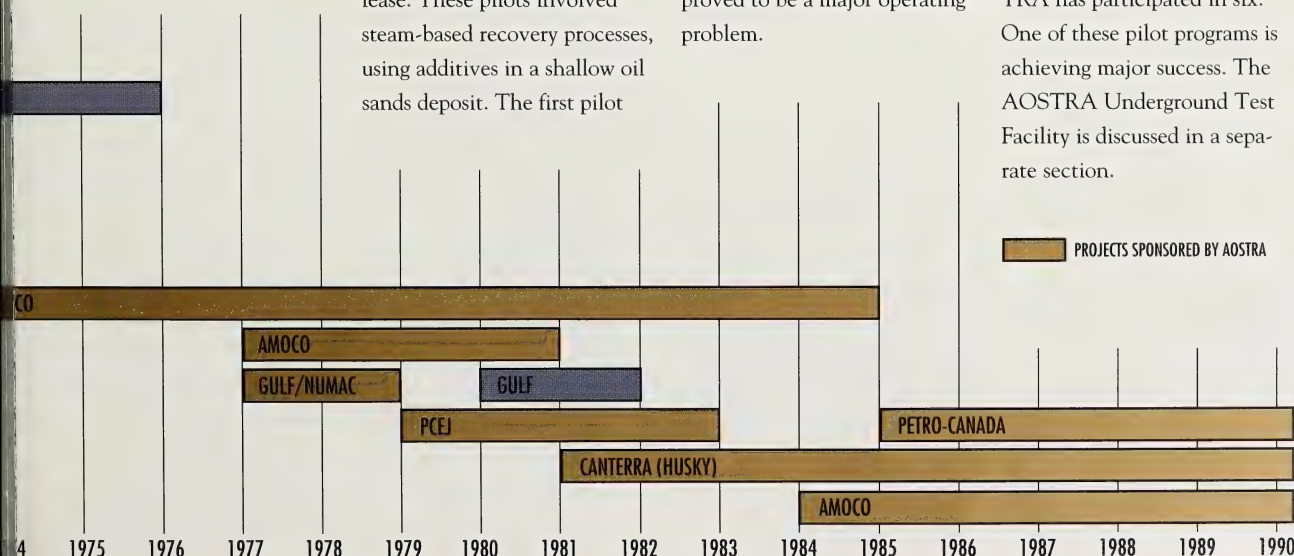
achieved in obtaining communication between the wells near the base of the pay zone. However, difficulty was again encountered in maintaining communication paths as the injection of steam commenced. Only limited hot communication resulted and the pilot was shut down early in the steam injection phase due to surface outbreaks of steam beside several wells.

In 1969, Suncor conducted a small inverted five-spot pattern combustion pilot in a shallow oil sands deposit near their surface mining operation. Results indicated that bitumen could be produced and communication achieved and maintained below fracture pressure by simultaneously injecting solvent and air.

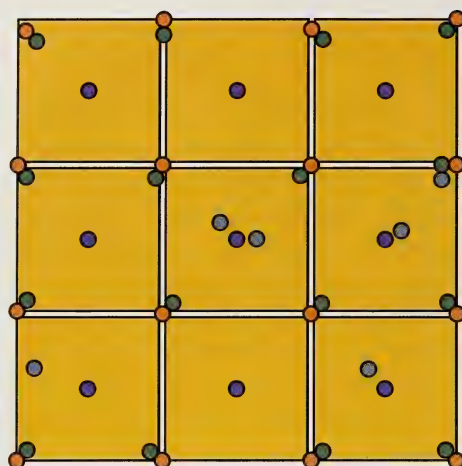
Texaco Exploration Co. Ltd., during the period 1973 to 1985, operated a series of three pilots at their Fort McMurray lease. These pilots involved steam-based recovery processes, using additives in a shallow oil sands deposit. The first pilot

was a nine-spot with central injection. Communication was achieved over a distance of 100 m. However, difficulty was experienced in developing communication within a reasonable time frame over longer distances. The second pilot consisted of a smaller, enclosed seven-spot with central and peripheral steam injection. With the reduced interwell spacing, good communication was found throughout the pattern. Once hot communication was achieved, principal recovery was by means of the injection of steam with naphtha. Pressure buildup and depletion cycles were employed and total recovery in excess of 50% of the oil-in-place was attained. The third pilot consisted of parallel horizontal wells which were drilled near the base of the McMurray deposit. Although the wells were successfully drilled, sand exclusion proved to be a major operating problem.

Although significant effort by the eight pilot operators and their partners had been expended to 1974, no technology breakthroughs had been confirmed. It was believed at that time that the main technological hurdles remaining to be overcome for Athabasca were the establishment and maintenance of effective communication in the base of the oil sands between wells on commercial spacing, together with demonstration of economical bitumen production rates and steam-oil ratios. One of the reasons why AOSTRA came into existence was to support continuation of the effort necessary to ensure that the technology required to unlock these vast reserves was developed. Since the formation of AOSTRA in 1974, eight additional pilot operations have been conducted in the Athabasca deposit of which AOSTRA has participated in six. One of these pilot programs is achieving major success. The AOSTRA Underground Test Facility is discussed in a separate section.



Gregoire Lake Block I in situ combustion well pattern with twin production and stimulation wells.



Among the first pilots in which AOSTRA participated, from its inception in 1977 to termination in 1981, was the Gregoire Lake Block I COFCAW project operated by Amoco with AOSTRA, Shell, Suncor, and Petro-Canada as partners. The project was designed to demonstrate the technical viability of the forward combustion with water process developed during previous pilot testing. The demonstration pilot consisted of nine 5-spot patterns drilled on 0.5 hectare pattern spacing with twice the interwell distance of the previous successful tests. In early pilots, where interwell distances were fairly close, communication between wells was achieved in the lower section. In the Block I pilot where the interwell distances were larger, the fractures worked their way up to the top of the oil sands before reaching the producers and communication was not achieved. Wet forward combustion could not be con-

ducted. Although the Block I pilot did not demonstrate the viability of the COFCAW process at commercial well spacing, it did provide valuable insight into the behaviour of fractured oil sands.

In 1977, Numac Oil and Gas, in conjunction with AOSTRA, Amoco, and Gulf Canada conducted hydraulic fracture tests in a highly bitumen-saturated oil sands section in an area where the overburden was about 315 m. Results of the fracture test were determined by injecting colored cement grout into the fracture and subsequent coring to determine the location of the fracture. These tests suggested that an initial horizontal fracture with 7 or 8 m radius was created. Beyond that radius the fracture turned upwards. It was concluded that in this area of the oil sands, fractures cannot be maintained horizontal at the low injection rates of 0.3

to 0.8 m³ per minute used in the test. This conclusion has been subsequently confirmed by various other fracture research programs supported by AOSTRA.

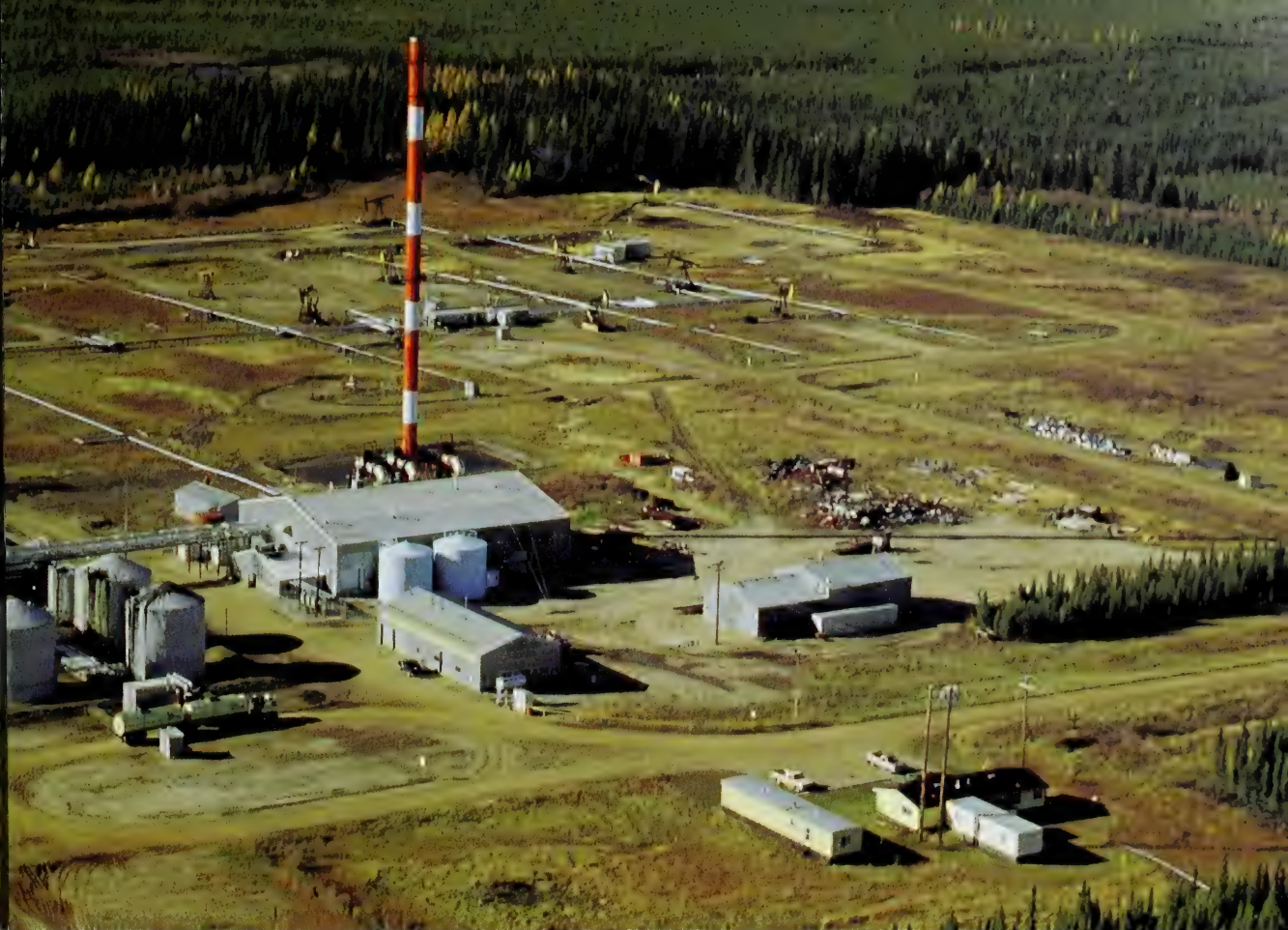
A very innovative electrical heating approach to establishing horizontal communication was field tested. The concept, involving electrically preheating the base of the oil sands by using the electrically conductive underlying water, was tested by Petro-Canada with partners Cities Service, Esso Resources, and Japan Canada at the Stony Mountain pilot from 1979 to 1983. The formation was first preheated by passing electrical currents through the formation from one well to another. Recovery of this preheated bitumen was then attempted by steamflooding. The formation was successfully heated. However, subsequent bitumen recovery was below expectations due to geological factors. Two other wells in the same area were steam stimulated. Although injectivity was good, subsequent production was disappointing. AOSTRA supported this effort through a licensing agreement to acquire the technology.

The largest and most successful in situ pilot in the Athabasca deposit is located at Kearl Lake. The project operated by Canterra Energy (now

Husky) with Tenneco (now Esso) and AOSTRA as partners involves the use of a modified steamflood. The project passed the one million barrel bitumen production mark in November 1989, becoming the first project in the Athabasca to do so and joined the ranks of other successful pilots such as Shell's Peace River In Situ Steam Project, which have subsequently become commercial operations.

At Kearl Lake, the recovery process, which consists of developing horizontal fractures to establish interwell communication, steamflooding from a central injection well, and steam stimulating production wells to obtain and maintain production, was developed





over a number of pilot phases, beginning in 1981. The first phase was a single inverted seven-spot pattern surrounded by injectors. Encouraging results were obtained. However, the time to reach peak production rates was longer than commercially acceptable. Next, improvements in the fracture design and heat-up strategy were made, based on first phase results and findings in several other research projects, sponsored by AOSTRA. Modifications to the startup procedure have been implemented in subsequent phases, first at an inverted nine-spot pattern beginning in 1984 and later at two five-spot patterns

in 1986. The largest volume fracture treatment conducted in Canada, used cold water to fracture at the base of the oil sands at one of the last two patterns. The other pattern was started by fracturing with steam. Although improved fracture design has resulted in fractures with significant horizontal components, injected fluids appear to migrate up the sand to layers which conduct fluids more easily. At Kearn Lake the layers with the reduced bitumen saturations are located at the top of the main oil sands which creates a steam override condition. Steam override at Athabasca has in the past been considered undesirable. The very good bitumen rates and steam-oil ratio performance at Kearn Lake,

however, is a significant achievement and demonstrates that bitumen recovery with steam override may have commercial application at Athabasca. The effect of initial fracturing on current performance however, has yet to be determined.

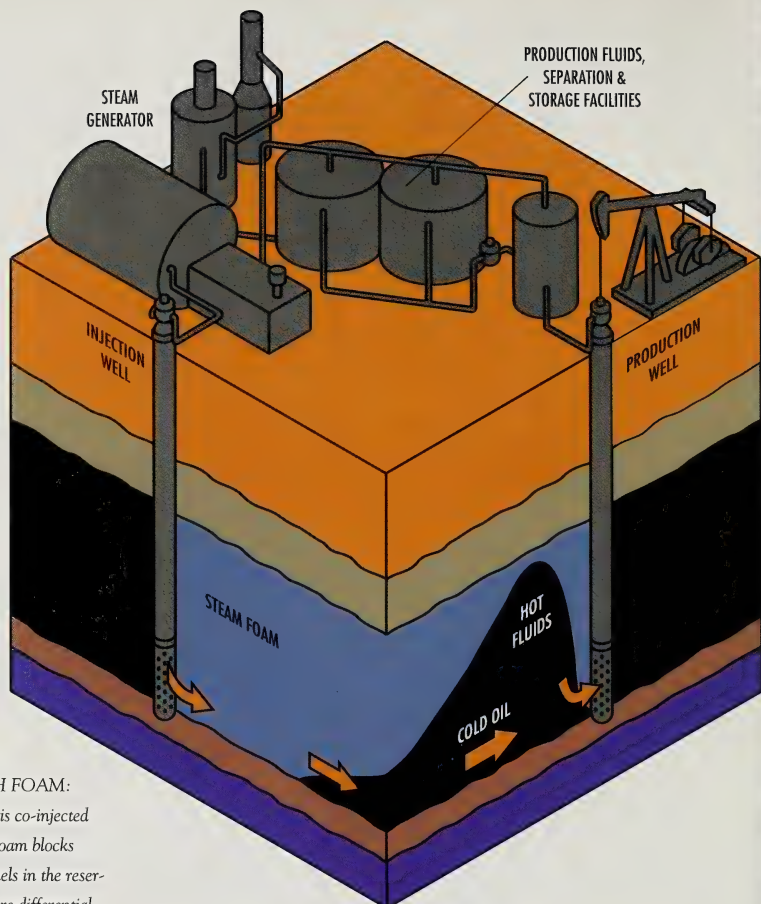
Lack of steam confinement to pilot areas often occurs in the Athabasca region. Steam confinement has been achieved at the Kearn Lake project by a new and novel technique under patent application. Reduced steam outflow from the pilot area has yielded a very significant increase in bitumen production.

The Kearn Lake pilot set a new record for in situ production of Athabasca oil sands bitumen with the millionth barrel.

Subsequent to the termination of the Amoco/AOSTRA Gregoire Lake Block I pilot in 1981, a steam test program was designed for the Gregoire Lake area. The resulting project, the Gregoire Lake In Situ Steam Pilot (GLISP), operated by Amoco with partners, Petro-Canada and AOSTRA, located approximately 15 km east of the Block I site was initiated in 1984. The pattern is a small inverted four-spot. Hydraulic fracturing to develop interwell communication through the oil sands was conducted and involved monitoring techniques including two types of tiltmeters, chemical tracers, elevation surveys, passive microseismic and two pressure-temperature observation wells. One of the fractures was propped with 560,000 pounds of sand and sets a record as the largest sand-propped fracture conducted in Canada. Owing to the isotropic in situ stress conditions existing at the depths of interest at this pilot and other stress effects created during fracturing, the direction of these fractures was found to be unpredictable. It was concluded that these fractures did not remain horizontal and interwell communication through the base of the oil sands was not obtained. Subsequent steam injection moved to an upper layer with lower bitumen saturation through

STEAM FLOOD WITH FOAM:
Foam-forming surfactant is co-injected with steam. The viscous foam blocks highly transmissible channels in the reservoir, increasing the pressure differential between injector and producer wells and improving sweep efficiency of the steam flood. The steam-foam injection program must be tailored to the recovery process and reservoir geology.

which it travelled to the production wells much like the Kearl Lake Project. Heat outflow from the pattern through this upper transmissible layer is detrimental to effective use of injected heat. At GLISP, foam surfactant, the first application of a surfactant in a thermal project in Canada, is being injected with the steam to reduce the mobility of the steam in this upper layer, thus diverting it to lower sections of the sand. This strategy is providing encouraging results to date. However, continued testing is required to confirm its long term benefits.



The foregoing pilots are located in areas where the oil sands are at a medium depth, in the order of 150 to 200 m. They involve the establishment of interwell communication by fracturing or electrical heating, as part of the recovery process, and flooding from injectors to producers using in situ combustion or steam. A number of other pilots in areas where the oil sands are more deeply buried, have tested the cyclic steam stimulation recovery process.

Gulf Canada conducted a number of steam stimulation tests during the period 1980 to 1982 on six wells in the

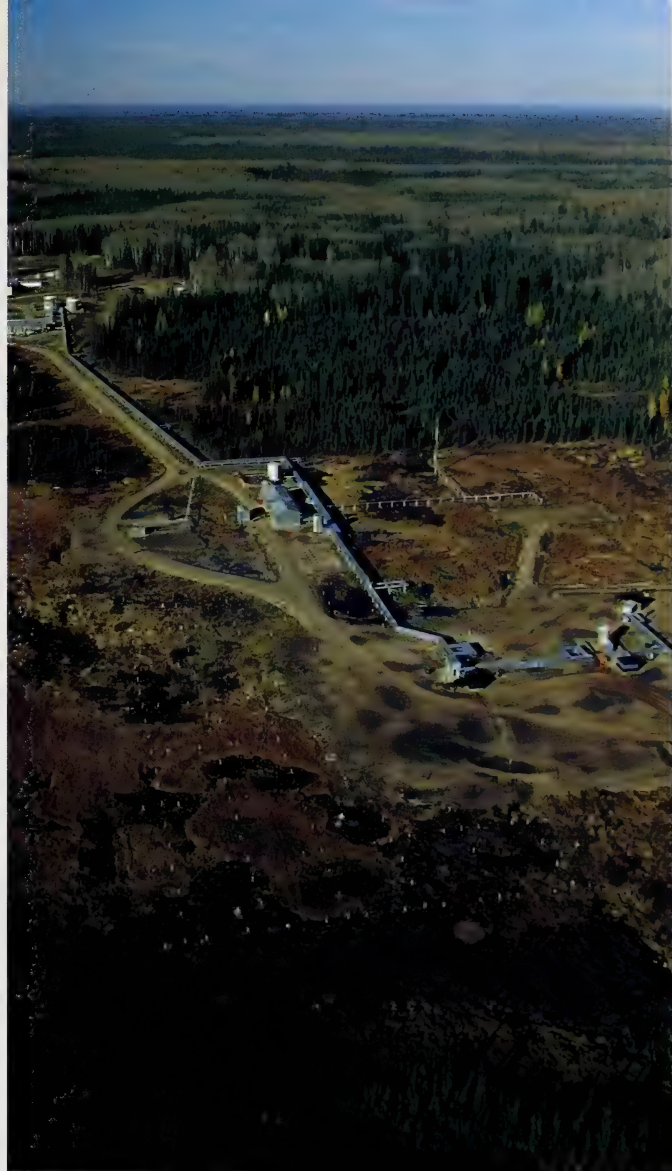
Surmont area where the oil sands are about 300 m deep. Petro-Canada with partners, Cities Service, Esso Resources, and Japan Canada have stimulated three wells by cyclic steam in the Hangingstone area starting in 1985, and the results have been very encouraging. Based on performance to date a multiwell cyclic steam stimulation pilot is being constructed by the Petro-Canada group.

In addition to financial and technical support provided to field pilots, AOSTRA also supports basic research through the ARC Core Research Programs, PRI Core Research Program, the University Access Program, and a number of other technology develop-

ment projects addressing specific areas. A great deal of the basic research is common to more than one deposit. Major efforts have been directed to the Athabasca deposit, particularly in research being conducted in the ARC Core and the University Access Programs. Under the University Access Program, for example, sixty-three projects addressing bitumen recovery from the Athabasca deposit have been undertaken since 1974 by thirty-nine research teams from nine Canadian universities. In addition to measuring bitumen properties, describing fluid flow in oil sands and developing upgrading technology, significant advances are being made in understanding the geotechnical properties of oil sands and the mechanisms whereby fractures are created.

Although a large number of in situ pilot tests and research projects have been conducted in the 60 years since J.O. Absher's proclamation, the key to unlocking the Athabasca reserves by in situ methods has not yet been found. Recent technological advances, however, suggest that a commercial in situ project for the medium depth Athabasca sands is in the offing. What is primarily needed is a better understanding of how to take advantage of

natural geological features in bitumen recovery processes. Further improvements in developing and maintaining interwell communication and in controlling heat loss due to fluid outflow from the project areas must also be demonstrated. Although technological advances in well design and operations have not been discussed, they too have been significant. Further advancements in technology in these areas will take place as projects progress to demonstration and commercial scales. Separation processes for bitumen and water emulsions and bitumen upgrading are also problem areas which must be addressed in order to improve the economic viability for in situ bitumen recovery in the Athabasca deposit.



At the Amoco/AOSTRA GLISP pilot, shown in the aerial view above, a technician monitors steam boiler operations.

THE LARGEST SINGLE HYDROCARBON ACCUMULATION IN ALBERTA — AND PERHAPS IN THE WORLD — THE ATHABASCA DEPOSIT — IS THE ONLY DEPOSIT IN THE PROVINCE WITH SOME RESERVES SHALLOW ENOUGH TO BE SURFACE MINED.

Leading the world in oil sands development, Alberta's two commercial oil sands plants surface mine 15% of Canada's total oil production using conventional open pit mining.

The deposit contains about 700 billion barrels of bitumen in place, 10% of which is close enough to the surface to allow the application of open pit mining. The two commercial surface mining plants in this area produce 15% of Canada's total oil production. The mined material is conveyed to a processing plant where the bitumen is separated using the Clark Hot Water Extraction Process.

Through intensive research great strides have been made in the development of the Hot Water Process. Bitumen recoveries of over 90% and record breaking production levels have established oil sands mining as a competitive method of oil production.

Improvement in the competitiveness of mined oil sands projects will require major technological innovations. Increasing operating depths and longer hauling distances,



poor recoveries from lower grade ores, and process environmental constraints are challenges which are currently being tackled.

AOSTRA's Mining and Extraction programs address the need to improve both the economics and the environmental impact of surface mineable oil sands recovery processes both through the improvement of current methods and by new technology development.



LEFT: The bitumen in the Hot Water Process is extracted using several gravity separations steps. Shown here is the primary separation vessel, where the majority of the bitumen is recovered.



IMPROVING OIL SANDS MINING METHODS

Dredging and Sludge Disposal:

The current method of mining oil sands accounts for over 40% of the total operating cost. AO STRA and others believed that substantial savings in the cost of overburden removal might be realized if conventional dry mining methods could be replaced by hydraulic dredges to dig and slurry the overburden for removal. This was the premise in the ongoing development of hydrotransport in an oil sands application.

In 1979, under contract to AO STRA, H.G. Stephenson Mining Consultants Limited completed a study which indicated a potential reduction in the unit cost of removing overburden through use of cutter suction dredging. The study indicated several areas of concern such as the stability of the stacked material and hydraulic performance of the dredge system. To address these concerns, AO STRA funded laboratory studies by Dr. M.B. Dusseault of the University of Alberta, to explore the relevant problems in dredging high fines

overburden such as the Clearwater clays and shales. During this same period, AO STRA and Petro-Canada Exploration Inc. jointly supported a program at the Delft Hydraulic Laboratory, in Delft, Holland. This program used a laboratory dredge to dig and pump oil sands and clay materials to evaluate the hydraulic transport characteristics and to determine the cutting forces necessary to cut siltstone occurring in the overburden.

Following completion of these preliminary studies, AO STRA maintained dialogue with Syncrude Canada Ltd. and others to stimulate some measure of field testing which all earlier work indicated was a mandatory next step.

In 1985/86, AO STRA and Syncrude Canada Ltd. carried out a large scale, two year field program. The focus of this program was on the disposal of the dredged overburden material. Experience in dredging and hydrotransport of silts and clays in ship channels had demonstrated that the dredged materials formed agglomerates or lumps during transport that could be disposed of in stable, trafficable spoil piles. It was believed that this phenomenon might permit the suspended

clay fines in tailings pond sludge to be co-deposited with dredged overburden as agglomerates. By operating an overburden dredge in a dredge pond composed of tailings sludge, the required intimate contact between sludge fines and clay shales in the overburden, prior to and during hydrotransport, could be achieved.

The test was conducted in 1985 using a machine supplied by Sceptre Dredging of Vancouver, who modified a standard 16 inch dredge for higher digging and pumping forces. Even with the modifications, the dredge had difficulty digging in situ Clearwater and Pleistocene clays. Production totalled 7,000 bank m³ (BCM) out of 40,000 BCM planned. Nevertheless, the test showed that the overburden could be dredged and spoiled (discharged and stacked in a slope) with fewer geotechnical problems than anticipated, when the dredge pond consisted of essentially clear water. However, a high fines loading in the dredge pond did not permit agglomerates to form and a stable, trafficable spoil pile was not created.

The objectives of the 1986 program were to evaluate the spoil performance with higher digging and pumping rates, and to use the data to conduct a feasibility study for commercial scale overburden dredging.

Overburden was excavated, screened to remove boulders and siltstone and recompacted into a barrier dyke across the dredge pond. The dredge excavated over 18,000 LCM (liquid cubic metres) of the rehandled material at rates of about 250 LCM per hour. The commercial feasibility study was conducted by Beaver Dredging of Calgary. The results of the 1986 program showed that:

As part of the Syncrude Canada Ltd./AO STRA dredging program, a specially modified dredge was used to evaluate the feasibility of dredging overburden.



- In situ overburden can be dredged, but at lower than anticipated production rates.
- Dredged material can be spoiled, provided fines build-up in the dredge pond can be controlled.
- Dredging with high fines fluid would require extraordinary measures to ensure stability.
- A fines settling pond would be required.

■ Both capital and operating costs for a commercial dredging operation were found to be higher than anticipated, approaching the costs incurred with conventional stripping methods.



Based on these conclusions and after careful review, Syncrude Canada Ltd. decided that further development work on dredging overburden in combination with tailings sludge was not justified.

A dual wheel cutter head is one of the many cutter head designs available in dredging technology currently under study in the OSLO/AOSTRA dredging and Cold Water Extraction of oil sands program.



The geotechnical experience gained from these tests served as the basis for a new AO STRA/Syncrude program based on the ability of dry-mined Clearwater clay shales in the overburden to absorb large quantities of water, often more than 100% by weight, before reaching the liquid limit of the clay shales. A laboratory investigation followed by large scale field trials was initiated by AO STRA and Syncrude in 1988 to determine the geotechnical properties of clay shale-sludge mixtures and to test various mixing methods which might be applicable in large scale operations.

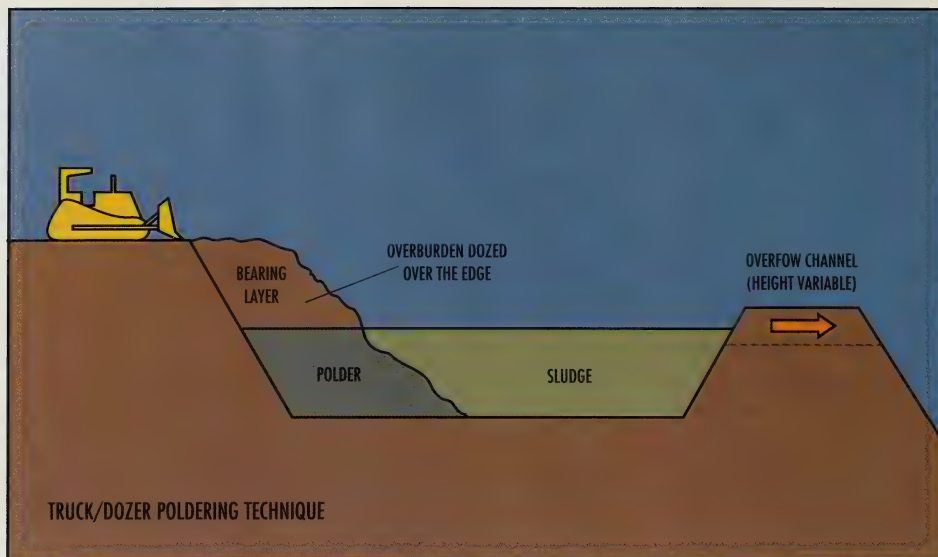
Dry mined overburden and sludge were mixed in the field in a confined spoil area (polder). This resulted in a soil structure that could be made to bear the weight of construction equipment if capped with a bearing layer of competent material. This positive field test result could be the basis of a potential scheme for disposing of sludge in an environmentally acceptable manner.

The Other Six Leases Operations (OSLO), a consortium consisting of Esso Resources Canada Ltd, Canadian Occidental Petroleum Limited, Gulf Canada Corporation Inc., Petro-Canada Inc, PanCanadian Petroleum Ltd., and Alberta Oil Sands Equity, estimated that significant cost

savings could be realized by dredging and hydrotransport of oil sands in combination with a cold water extraction process.

A short duration oil sands dredging and slurry pipelining test was carried out at Syncrude Canada's Mildred Lake site by OSLO and AO STRA in 1986, in which 500 m³ of rehandled oil sands were dredged and piped to a disposal area. This preliminary, short term test indicated that pumping and slurry pipelining of dredged oil sands with air and chemical injection had potential as an oil sands mining and conditioning technique in which bitumen might be liberated and recovered at ambient temperature. The encouraging results of this early field test added to the incentive for both AO STRA and the OSLO organization to continue to investigate the technical feasibility of the OSLO Cold Water Extraction Process.

The development of oil sands dredging and the OSLO Cold Water Extraction Process have been the subject of an ongoing multi-year research and development project, being carried out by OSLO and AO STRA, since 1987. This program initially involved construction and operation of a laboratory scale dredging, pipeline conditioning, and bitumen recovery system in Calgary; simulation of dredge pond de-icing methods at Esso Resources test basin in Calgary; and both batch and continuous flow field pilot operations on Lease 41 near Fort McMurray, Alberta. Preliminary engineering and cost studies have been prepared for a 800 ton per hour Minimum Size Demonstration Plant which is presently under consideration by AO STRA and the OSLO organization. If successful, this demonstration facility could pave the way for new and cost effective approaches to oil sands mining and bitumen extraction.



ABOVE: The pressing need for finding a suitable sludge disposal method initiated the Syncrude Canada Ltd./AO STRA field test which demonstrated the feasibility of co-deposition of sludge with overburden in a confined spoil area (polder).

BELOW: The high absorption of water by the overburden clay shales results in a mixture that when capped with a layer of competent material, can readily support heavy equipment.

Borehole Mining:

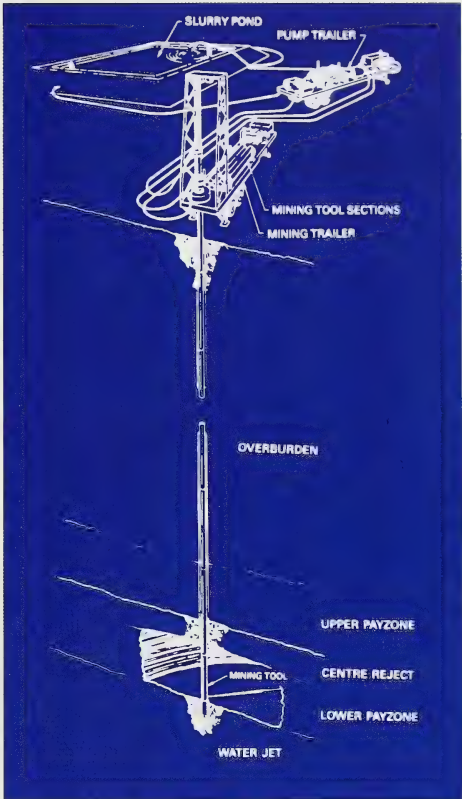
There are vast quantities of bitumen which are at a depth between 100-300 m. This bitumen cannot be extracted economically by conventional surface mining techniques or by in situ methods currently being used successfully by industry.

OSLO leases contain 17 billion barrels of bitumen within the 100-300 m depth range. In order to prepare for the exploitation of this vast resource, OSLO, with the participation of AOSTRA, has been developing the technical features of a borehole hydraulic mining process to mine oil sands by means of a high pressure jet operating in sub-surface chambers in the oil sands formation. This technique incorporates the synergism of hydraulic mining with the OSLO Cold Water Extraction Process, being developed in conjunction with dredging of surface mineable oil sands. The technical innovation of the system is an extendable arm jetting device that is lowered through a conventional drill hole into the oil sands zones where it excavates a cavity using a rotating water jet. Liberated bitumen and water flow to the surface leaving behind the solids in a stable, water filled cavity. The program was initiated in 1988 and consisted of



jetting tests in air and under water, both in laboratory and field experiments; development of a new extendable arm jetting device; and evaluation of drilling tools and techniques. The second year of the program consisted of laboratory testing of a quarter-scale model of an extendable arm, purchase and refurbishing of a borehole mining system, field testing on Lease 41, and computer modeling of cavity behaviour.

The results to date show definite promise. Jet cutting pressures are much lower than anticipated and oil sands outcrops at the surface, which were excavated by the water jet, were stripped of bitumen leaving clean sand at the bottom.



Future work includes continued development of the extendable jetting arm, more field testing on OSLO's Lease 41, geotechnical and process modelling and the development of a semi-commercial source test proposal. The borehole mining system, if technically successful, may provide an economical and environmentally acceptable method for mining deep oil sands. Higher bitumen recoveries than those obtained by steam injected in situ recovery methods in shallow reservoirs may be realizable.

ABOVE LEFT: This surface borehole mining test on oil sands provided critical fundamental data for a planned OSLO/AOSTRA deep in situ borehole mining test. ABOVE: A conceptual arrangement of a commercial scale application of borehole mining. The system is highly compatible with the Cold Water Extraction Process and preliminary economics indicate a competitive mining and extraction alternative.

TOWARDS MORE EFFICIENT BITUMEN EXTRACTION

Commercial recovery of bitumen from the Athabasca deposit is currently achieved using the Clark Hot Water Process. The process is based on gravity separation of bitumen from sand with some addition of air to promote bitumen flotation. Oil sands are conditioned in a rotating tumbler in which the oil sands are mixed

with hot water (95°C), steam (for temperature control), and sodium hydroxide (caustic). The caustic enhances the bitumen liberation process.

Although proven commercially successful, the process has the following drawbacks:

1. Recovery of bitumen drops off sharply at lower ore grades.
2. The process, through the use of caustic, disperses clays present in the feed material.

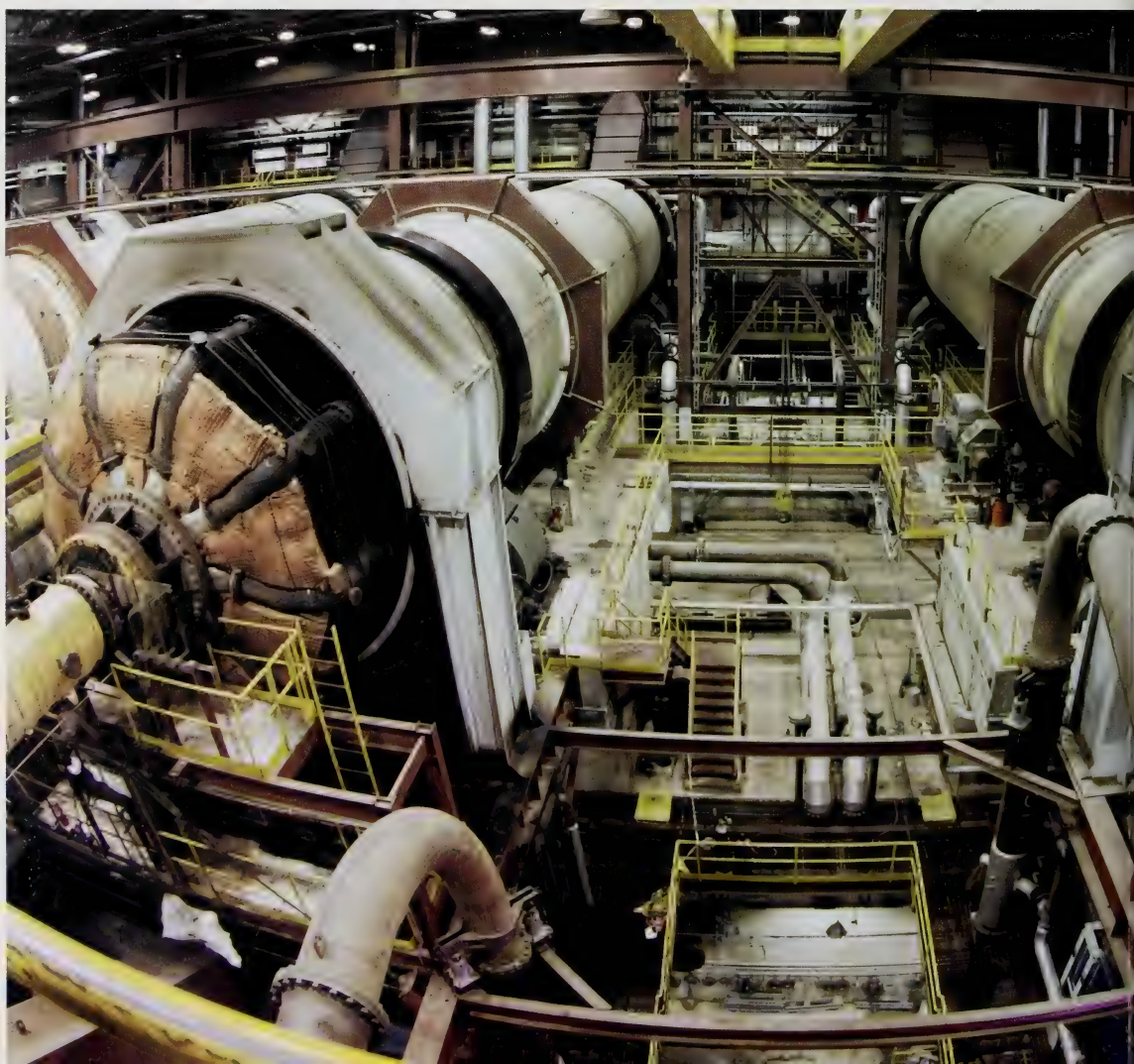
This generates a fines sludge which must be stored in large ponds for settling. Eventually a method of permanent sludge disposal must be found. In spite of ten years of research effort, an environmentally acceptable manner for sludge disposal has not yet been developed.

3. The process is energy inefficient. All of the incoming feed including the recycled water must be heated to process temperature but only 10% by weight of the oil sands feed is

recovered. The remaining 90% is discharged into tailings ponds.

4. Bitumen is lost to tailings and to oversize reject material.

The challenge of current and future extraction processes is to minimize or eliminate these deficiencies. AOSTRA, over the last fifteen years, has supported the development of new technologies which address some or all of these deficiencies.



The commercial Hot Water Process uses large rotating tumblers to mix and condition the oil sands for further processing.

Direct Thermal Processing:

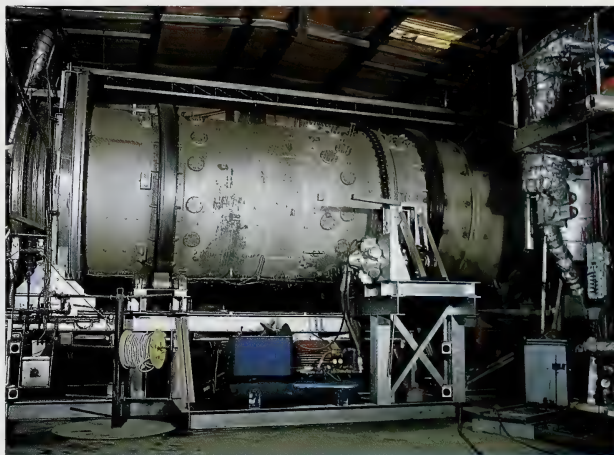
Since 1976, AOSTRA has pursued the development of methods by which whole oil sands might be processed by thermal retorting to effect conversion of bitumen and recovery of hydrocarbons as a bottomless (i.e. residue-free) distillable oil. In other words, processes which provide for the simultaneous extraction and primary upgrading of oil sands bitumen.

In 1976, AOSTRA commissioned a study to conduct a preliminary evaluation of the comparative economics of the Lurgi-Ruhrgas direct distillation process and the most advanced hot water process in combination with fluid coking. Further to this study, AOSTRA entered into an agreement with Lurgi Kohle und Mineralöltechnik GmbH to carry out a test run in September of 1979 on a pilot unit in Essen, West Germany. The results of the tests did not fully confirm earlier performance predictions. AOSTRA commissioned a re-evaluation of the comparative economics based on actual pilot data. The results of this re-evaluation indicated that no further work was warranted by AOSTRA at that time.

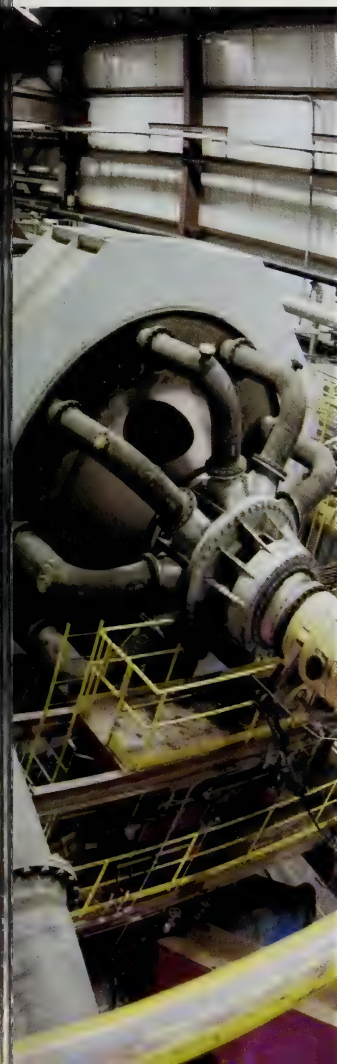
In contrast, the AOSTRA Taciuk Process is a true success story. The development of this technology has proceeded without interruption since 1977. The AOSTRA Taciuk Process, which is owned by AOSTRA, has been developed in conjunction with UMA-TAC Industrial Processes Division of UMA Engineering Ltd. The Process, invented by an Alberta engineer, William Taciuk, is a thermal retorting process which accepts run-of-

mine oil sands feed and produces cracked petroleum distillates, dry, oil-free tailings, off-gas, and process waters. The principal process operations occur in a single, horizontal rotating vessel, called the AOSTRA Taciuk Processor.

The AOSTRA Taciuk Processor at the Calgary pilot plant has tested over 15,000 tonnes of feed in over 350 tests ranging up to 150 hours of continuous operation.



The pilot facilities include batch testing for feed characterization.



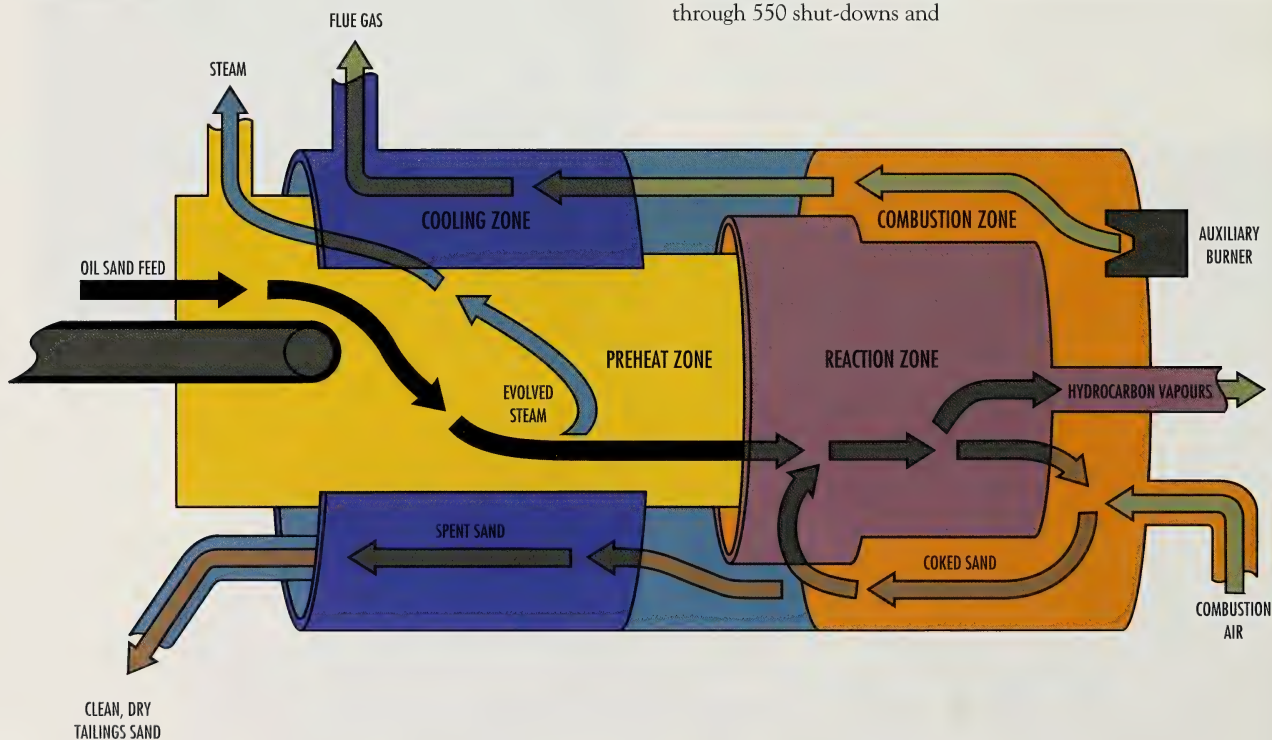
The AOSTRA Taciuk Direct Thermal Processor for retorting mined oil sands and oil shales, simultaneously extracts and upgrades bitumen, producing a thermally cracked oil and dry tailings. These operations are accomplished in a single horizontal rotating vessel consisting of individual compartments or "zones" designed to perform the processing steps required to recover and separate the various product streams. The processor is also attractive for processing oil shales and cleanup of hydrocarbon and PCB-contaminated soils.

The AOSTRA-owned 105 tonne/day continuous flow pilot plant in Calgary has processed successfully over 15,000 tonnes of oil sands and other candidate feeds. This operating experience has confirmed the operational and performance characteristics of the process and has led to the evolution of a design which provides technical and economic benefits over current commercial mined oil sands projects.

The Processor has proven itself with its unique feature of simplicity of design, absence of internal moving parts, rugged construction, and demonstrated solids/solids heat transfer capacity. Its safety and reliability have been demonstrated through 550 shut-downs and

start-up cycles, and 8,000 hrs of operation in over 350 tests ranging up to 150 hrs of continuous operation.

The AOSTRA Taciuk Process system is ready for field demonstration in an oil sands application and AOSTRA continues to discuss the use of the process for mined oil sands applications with lease holders and other poten-



THE PREHEAT ZONE

The hot spent sand and combustion flue gases indirectly heat incoming fresh feed while connate water is evaporated and light hydrocarbons are recovered. The frozen materials are ablated and oversized feed material and rocks are removed.

THE REACTION ZONE

The pre-heated oil sands are mixed with hot recycled sand from the combustion zone. This resulting temperature thermally cracks the bitumen, yielding a hydrocarbon vapour product and coke-coated sand particles. The hydrocarbon vapour product is condensed external to the processor, yielding liquid product oils which may be pipelined, hydrotreated, or sold as fuel oil.

THE COMBUSTION ZONE

Air is introduced to burn the coke from the coke-coated sand to increase the temperature of the recycled sand. Auxiliary burners supply supplementary heat, if required. A portion of the hot sand in the combustion zone is recycled to the reaction zone while the balance of the sand and the combustion flue gases flow to the cooling zone.

THE COOLING ZONE

The temperature of the hot sand and the flue gases are reduced by indirect heat transfer to the incoming fresh feed. The hydrocarbon-free tailings sand is discharged, quenched, and transported to previously mined-out pit areas. The flue gases are discharged to a treatment system for removal of fine solids and SO_2 .

tial industrial users in an effort to attract participation in a large scale field demonstration. The process advantages over existing oil sands extraction methods are numerous and include:

- Increased product yield
- Simplified process flow
- Elimination of hydrocarbon losses to tailings and rejects
 - The need for tailings ponds is eliminated
 - Greater energy efficiency
 - Lower capital and operating costs
 - No chemicals or additives required

The two other applications of the AOSTRA Taciuk Process, the processing of oil shales and treatment of hydrocarbon-bearing solid waste materials, continue to generate a substantial degree of interest.

As a result of favourable test results obtained from processing of 1600 tonnes of oil shale from the Stuart Deposit of Queensland, Australia in 1987, AOSTRA entered into an agreement with Southern Pacific Petroleum (SPP) and Central Pacific Minerals (CPM) under which SPP/CPM may construct a 6000 ton per day semi-commercial oil shale demonstration plant to confirm process performance prior to full-scale commercial use. Plans for construction of this demonstration plant are now being finalized.



Pictured above is the first commercial AOSTRA Taciuk Process Plant, commissioned in 1989. LEFT: Standing in the foreground are inventor William Taciuk (left) of UMATAC Industrial Processes with Mr. Douglas P. Komery of AOSTRA.

Solvent Extraction:

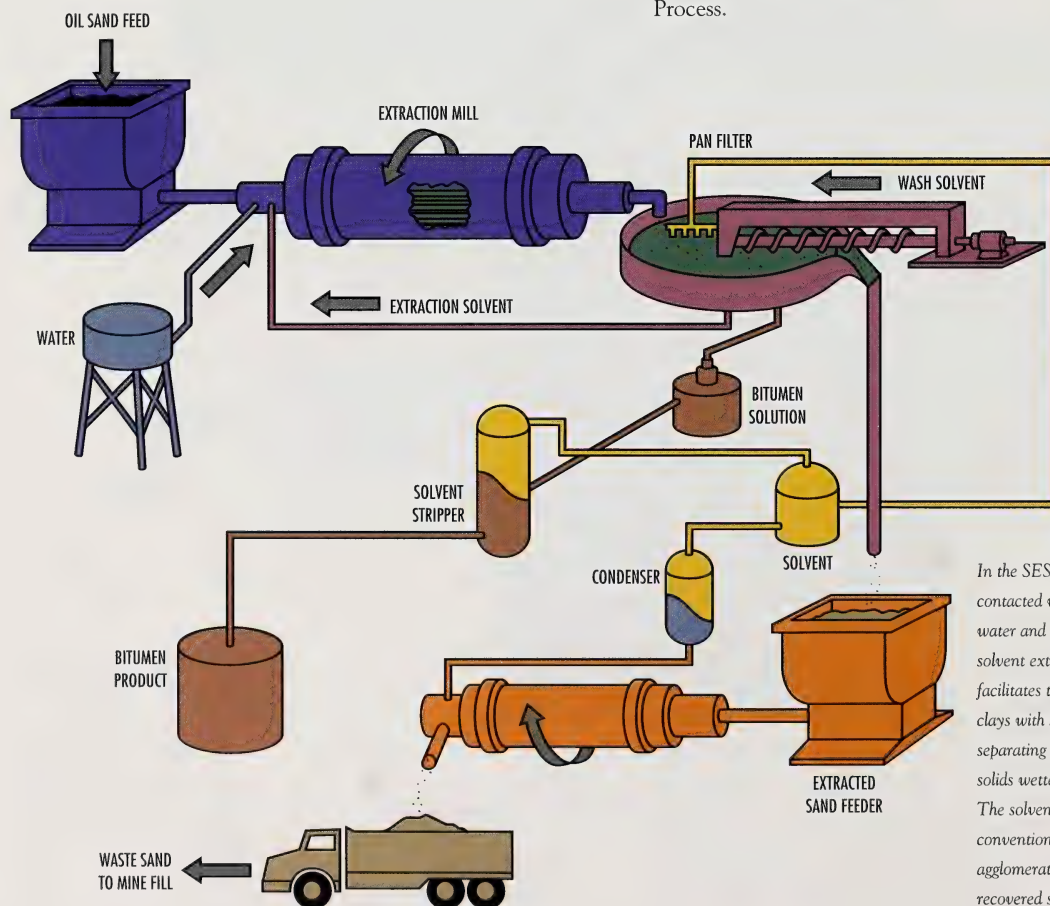
Solvent extraction is an efficient method for removing the bitumen from oil sands. In fact, the bitumen content of oil sands is defined as the material which can be extracted by aromatic solvents in a controlled laboratory extractor. Research work has been carried out in the past in an attempt to scale-up the laboratory extraction technique to commercial-size equipment. Two major concerns which have been identi-

fied are losses of solvent on the rejected sand and the need for vapour-tight equipment. Many proposals for development of a solvent extraction process have been submitted to AOSTRA.

The Dravo Process is based on a continuous, rotary percolation-type solvent extractor. In 1985, prior to undertaking any experimental programs, Dravo Engineers, Inc., prepared for AOSTRA, a design and cost estimate for the appli-

cation of the Dravo Solvent Extraction Process to the recovery of bitumen from mined Athabasca oil sands, prior to undertaking any experimental programs. The results of the Dravo study indicated that both capital and operating costs of a Dravo-based mining operation are significantly higher than those of a hot water extraction-based operation. As a result of this evaluation AOSTRA chose not to participate in further development of the Dravo Process.

During 1986 and 1987 AOSTRA, Shell Canada Ltd., and Solv-Ex Corporation participated in a project to test the performance of the Solv-Ex Process for the extraction of bitumen from oil sands and to determine capital and operating costs for the construction and operation of a demonstration plant on Shell's surface mining lease in the Athabasca deposit.



In the SESA Process, mined oil sands are contacted with controlled amounts of water and solvent in a rotating drum. The solvent extracts bitumen while water facilitates the agglomeration of the fine clays with sand. In a series of solids-liquids separating steps, diluted bitumen and solids wetted with solvent are produced. The solvent in the bitumen is recovered by conventional methods. The solvent in the agglomerates is recovered in a dryer. The recovered solvent is recycled to the process and the agglomerates are trucked or conveyed to mine pits for disposal.

The Solv-Ex Process is a development of the Solv-Ex Corporation of Albuquerque, New Mexico and is essentially a solvent-assisted hot water process. The feed oil sands are mixed with water and solvent in a staged counter-current process circuit. The process discharge streams are bitumen product and damp solids with some solvent. Most of the process water and solvent are recovered for re-use.

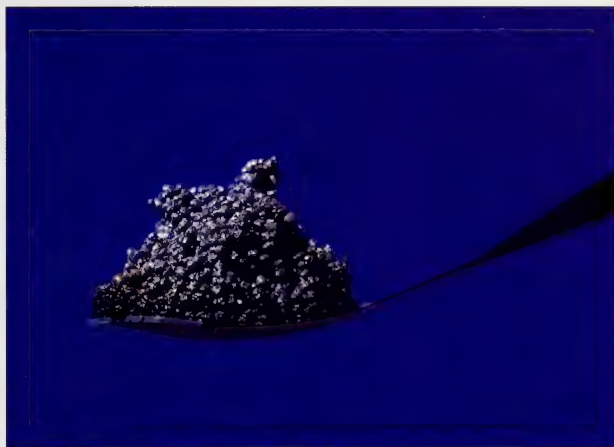
Phase I of the program was conducted in a one tonne/hour pilot plant in Albuquerque using 1200 tonnes of oil sands from Shell's lease near Fort McMurray. Phase II of this project consisted of the preparation of engineering designs and capital and operating costs estimates for a 1200 m³/d semi-commercial demonstration plant. In 1988, AOSTRA completed its evaluation of the pilot plant data and semi-commercial demonstration plant proposal. As a result of the evaluation, AOSTRA concluded the Solv-Ex Process requires further development and testing at the laboratory level before it would be ready for scale-up and semi-commercial demonstration.

In 1987, AOSTRA and the National Research Council of Canada (NRC) entered into an agreement to participate with Terra Energy Ltd in the preparation of engineering designs and cost estimates for a

demonstration plant to test the Solvent Extraction Spherical Agglomeration (SESA) process for the extraction of bitumen from mined Athabasca oil sands.

The SESA process had been developed and piloted on a laboratory scale by NRC. The process involves contacting mined oil sands with carefully controlled small amounts of water and a naphtha solvent in a rotating drum. The naphtha solvent extracts the bitumen while water facilitates the agglomeration of the fine clay minerals with the sand particles. In a series of solids-liquid separating steps, bitumen diluted with solvent naphtha and a tailings of agglomerated solids wetted with naphtha solvent are produced. The solvent is recovered from the bitumen by conventional refinery methods and from the tailings by evaporation. The recovered solvent is recycled to the process. The damp agglomerates can be transported by trucks or conveyors to the mined-out pit for disposal. An additional advantage of the process, is the high bitumen recovery achieved with lower grade oil sands.

Terra Energy has been granted a license by Canada Patents and Development Limited (CPDL) to develop and operate a SESA demonstration plant. The preliminary process design, material and



SESA is a bitumen recovery technology that offers complete recovery of fine clay minerals with sand particles as dry agglomerates. The agglomerate particles range in size from 0.5 mm to 1.5 mm.

energy balances, and cost estimates for a 10 tonne per hour demonstration plant are complete.

AOSTRA and NRC are currently proceeding with the detailed engineering and cost estimates for the construction and operation of the 10 tonne per hour demonstration plant to be located at a suitable site near Fort McMurray.

Terra Energy are pursuing with industry and other potential investors, the financing of the construction and operations of the proposed demonstration plant.

Pictured at right is the OSLO/AOSTRA dredging and Cold Water Extraction pilot on Lease 41. Oil sand is dredged at ambient temperatures as shown below.



RIGHT: Bitumen is recovered in conventional separation vessels using a novel combination of controlled air injection and chemical addition. High bitumen recoveries and product quality are attained, even with poor quality oil sands. A quick, natural settling of tailings is achieved, as shown in the Lease 41 sample on the opposite page.



Innovations in Water Based Bitumen Extraction Processes:

Ever since the start of commercial operation, improvements to the hot water process have been pursued by industry. AOSTRA has participated in several projects which utilize the hot water extraction, gravity settling technique, but offer innovations to improve the thermal and mechanical efficiency of conditioning to create a more environmentally acceptable tailings byproduct,

to provide higher bitumen recovery and to lower unit cost production

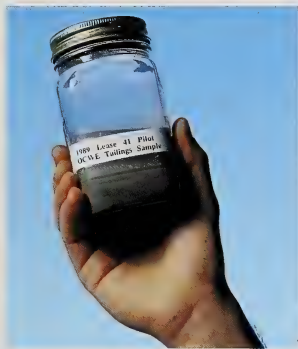
The R.T.R. Process is a modified hot water extraction process that offers mild oil sands conditioning and internal water re-circulation. A solvent/water contacting device is employed to remove residual solids and water from the primary froth, yielding a diluted bitumen product.

In 1983, AOSTRA entered into an agreement with Gulf Canada Resources Inc. and RTR-Rio Tinto Til Holding, S.A. to receive data from a pilot project located at the Suncor Inc. plant site. The results of the field tests were received for internal process evaluation.

IMPRO Engineering Ltd. created a bitumen extraction process based on a gentle slurring of bitumen with hot water. The gentle slurring would minimize the formation

of emulsions and thereby improve recoveries. In 1984 a 100 kg/hr test facility was constructed and various flow configurations were examined. The program was completed in 1985. Overall the process performed less satisfactorily than expected both in operation and recovery as compared to the hot water process.

Efforts today are focused on the development of the Cold Water Extraction Process. This process combines the cost



effectiveness of dredge mining with a cold water process which involves in-line air injection, chemical addition with conventional flotation techniques.

AOSTRA and the Other Six Leases Operations (OSLO) group have funded the first three years of a multi-year project, to develop the Cold Water Extraction Process as discussed previously. This process is currently showing great potential and could pave the way for future oil sands development.

Waste Stream Hydrocarbon Recovery:

The percentage of the total bitumen contained in the oil sands feed to the Syncrude Canada Ltd. and Suncor Inc. plants which is discharged with the extraction process tailings is relatively small. However, after many years of operations, millions of barrels of bitumen have accumulated in the sludge layers of the existing ponds. The amount of bitumen presently contained in the tailings ponds at Suncor and Syncrude plants is estimated at 120 million barrels. Both Suncor and Syncrude will be transferring the sludge to other locations in the future. This transfer period would provide an opportunity to recover this hydrocarbon resource.

With the assistance of AOSTRA, a promising process has been developed to recover this bitumen, called the Oleophilic Sieve Process. The process, invented by Alberta inventor Jan Kruyer at the Alberta Research Council, is a novel extraction concept whereby agglomerated bitumen is captured on the oleophilic surfaces of a perforated continuous belt, while water and solids are allowed to pass through belt openings. Other aspects of AOSTRA's involvement in this invention are

described in the section "Assistance for Inventors." Initially AOSTRA funded the testing of a small laboratory pilot. During the period between 1982 and 1984, tests were conducted on low grade (high clay content) oil sands. These tests illustrated the potential for using the Oleophilic Sieve Process for removing bitumen from tailings produced by the Hot Water Extraction Process. To further evaluate the process, AOSTRA and Suncor Inc. funded, on a 75-25 basis, respectively, the Oleophilic Sieve Development Company of Canada Ltd. (OSDCL) to test and develop the Oleophilic Sieve Process for extracting hydrocarbons from the tailings sludge produced by the Hot Water Extraction Process.

The project consisted of two phases. Phase I entailed engineering procurement, construction, and performance testing of a one ton per hour continuous flow pilot plant in Edmonton and was completed in May 1985. Phase II entailed skid mounting the pilot and relocating it to the Suncor plant site near Fort McMurray for extended testing on various sludge streams. Phase II was completed in November 1985 and the results showed that hydrocarbons could successfully be extracted from the Hot Water Extraction Process tailings sludge.

Today, acting on an initiative taken by Suncor Inc. and Syncrude Canada Ltd., AOSTRA is participating on an equal share basis in a comparative screening study to evaluate the costs and benefits of four processes for recovering bitumen from the Hot Water Process tailings pond.

One of the processes being evaluated is the Oleophilic Sieve Process. Phase I of the study included the definition of study parameters, establishing the physical and chemical characteristics of the bitumen to be recovered, quality objectives for the recovered bitumen, and economic parameters. Phase II of the study, now nearing completion, includes a detailed technical and cost evaluation of the four candidate processes.

A study of this section clearly demonstrates that AOSTRA has been intensively involved in developing new technologies for recovering bitumen from the near-surface oil sands deposits in the great Athabasca formation.

WHEN AOSTRA WAS FOUNDED IN 1974, SURFACE MINING OPERATIONS IN ATHABASCA WERE AT THE COMMERCIAL DEMONSTRATION STAGE. GREAT CANADIAN OIL SANDS (LATER SUNCOR) HAD BEEN PRODUCING FOR SEVERAL YEARS, AND THE HUGE SYNCRUDE PLANT WAS UNDER CONSTRUCTION. HOWEVER, THIS TECHNOLOGY WAS SUITABLE FOR APPLICATION TO ONLY ABOUT 10% OF THE DEPOSIT. THE DEVELOPMENT OF IN SITU TECHNIQUES AND STRATEGIES FOR ACCESSING THE BULK OF THESE VAST RESERVES BECAME A CORNERSTONE OF AOSTRA'S MANDATE.



Located 60 km north of Fort McMurray, Alberta, the Underground Test Facility (UTF) project is pioneering markedly new approaches to in situ bitumen recovery.

In 1976, a Calgary engineering firm, Williams Brothers Canada Ltd., proposed the study of a shaft and tunnel access scheme for in situ recovery from Athabasca. AOSTRA was one of the sponsors of this original Mine Assisted In Situ Process (MAISP) study which investigated adapting Russian thermal mining experience to the more difficult Athabasca situation. The shaft and tunnel

access approach had as its original objective the "missing zone" in Athabasca, i.e. the vast reserves in those regions of the McMurray formation which were too deep for surface mining extraction operations and too shallow for in situ methods being developed at the time. The key feature of this new approach was to place horizontal wells low in the McMurray formation to drain the heated bitumen. Mine access provided for the economical placing of sufficient wells to give extensive contact with the formation so as to bring about effective heating and gravity drainage.

When the industry group subsequently initiated the first small scale escarpment tests of MAISP, AOSTRA moved on to studies of a larger demonstration project. However, neither the MAISP surface tests nor additional AOSTRA/industry project studies led to an active industry interest in an underground test of the technology.

AOSTRA continued to be of the opinion that some good prospects for the technology could only be evaluated through full underground testing, and in early 1983 took the initiative on its own to develop detailed designs for an Underground Test Facility (UTF) project to be located on a Crown lease just beyond the limits of conventional surface mining methods.

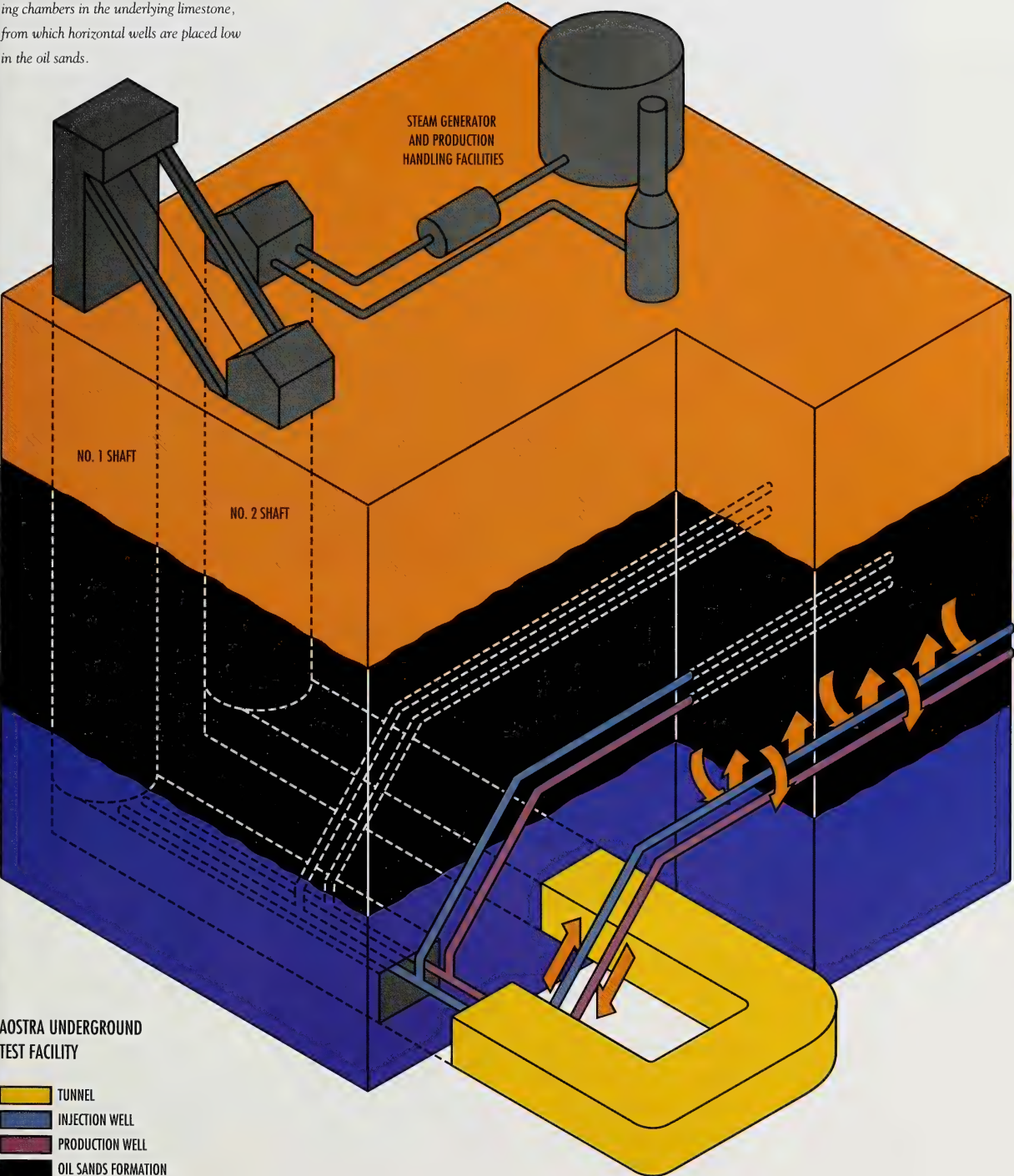
PROJECT DESIGN

The project concept is shown schematically on the facing page. Mine access consists of two vertical shafts sunk through the oil sands to a depth of over 200 m, from which a tunnel system was constructed in the Devonian limestone underlying the oil sands. The main hoist for personnel, mineral, and equipment is located in the No. 1 shaft, which also serves as the fresh air intake for the mine. No. 2 shaft serves as the mine exhaust and houses a slower moving Universal hoist intended for emergency egress only.

A custom made underground drilling rig was designed and built to drill upwards from the tunnel system and then horizontally through the oil sands. Three pairs of wells were drilled and completed for the Phase A program, each well approximately 160 m long, with the last 60 m being one of three test design completions. Each pair consists of a producer lying near the base of the oil sands and an injector about 5 m above the producer.

Process steam generation and production handling facilities are located on the surface with all process piping connecting to the wellheads through the No. 2 shaft.

Shafts and tunnels provide access to drilling chambers in the underlying limestone, from which horizontal wells are placed low in the oil sands.



AOSTRA UNDERGROUND TEST FACILITY

- TUNNEL
- INJECTION WELL
- PRODUCTION WELL
- OIL SANDS FORMATION
- DEVONIAN LIMESTONE

The development of the process technology for horizontal well in situ recovery is of course the end objective of the project. The first process selected for testing at the UTF was an application of the steam-assisted gravity drainage (SAGD) process, shown in simplified terms below.

As noted previously, each test pair consists of a producer near the base of the oil sands with an injector about 5 m above it. The diagram below is a cross section through the run of these wells.

Steam is injected through the upper well and flows through the highly permeable

Since steam is not forced into the formation above fracture pressure, it is contained within the developing steam chamber providing for good sweep efficiency and the economical use of steam. Theoretical forecasts of process performance were for high recovery at an excellent steam-oil ratio (SOR). The controlling unknown is the effective vertical permeability of the formation and its impact on the rate of production. These factors are principal subjects in our ongoing field tests.

A second process was added to the field program, Chevron's heated annulus steam drive process, or HASDrive. It combines features of SAGD gravity drainage with a controlled steam drive to effectively drain the formation.

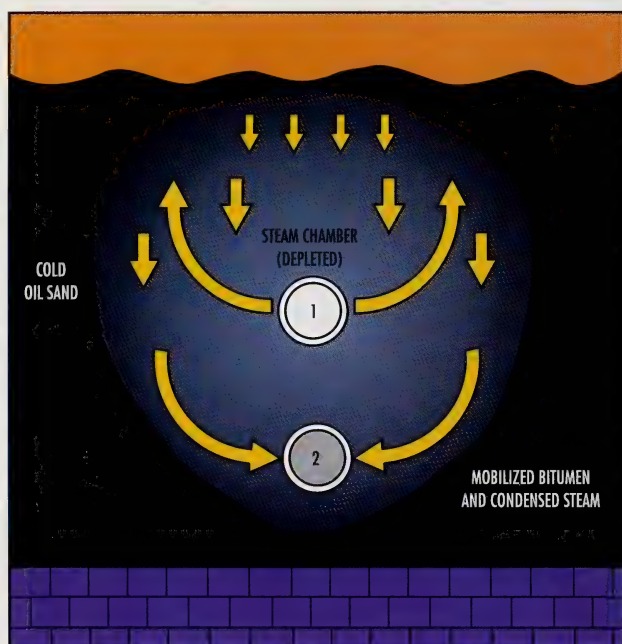
ACHIEVEMENTS

To date, the development program has enjoyed marked success. The mining access and underground drilling technology have been demonstrated; the in situ recovery processes are giving outstanding results; and there are strong indications that the potential exists for a viable commercial scale facility on the UTF site.

Mining/Drilling:

The shaft and tunnel access concept presented some major new challenges to the Canadian mining and drilling industry. Shafts had to be sunk through the oil sands, a formation that had completely foiled a previous attempt by others some twenty years ago. Unknowns associated with tunnelling included optimum horizon, required support, the possibility of gas and water emissions, and the effect of process heating on the overall mine integrity. The underground drilling and completion of large diameter horizontal process wells had never been attempted before.

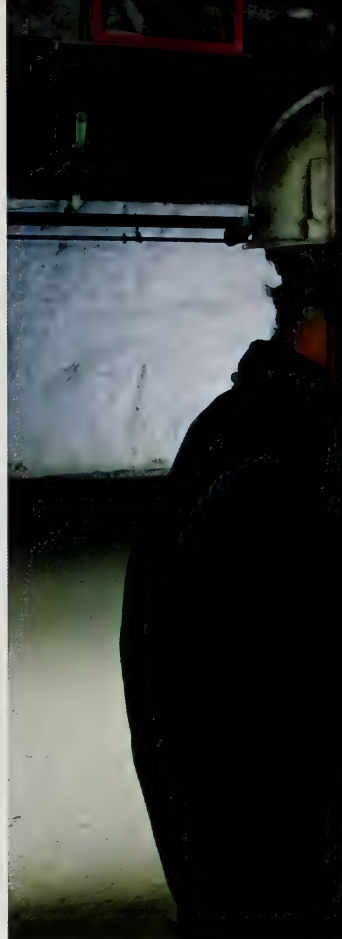
These challenges have been met.



- 1 INJECTION WELL
- 2 PRODUCTION WELL

The Steam-Assisted Gravity Drainage (SAGD) process field tested at the UTF has demonstrated the effectiveness of gravity forces in contacting and draining an oil sands reservoir.

depleted zone to the cold oil face where it is condensed and gives up heat to the sand and bitumen. The mobilized bitumen and condensate drain by gravity to the lower production well. The depleted zone, or steam chamber, rises and spreads as the pay zone is effectively exploited.





The main shafts were sunk by blind shaft boring, a method new to Canada, in which the shafts were literally drilled like huge oil wells. One of the largest conventional drilling rigs was extensively modified to handle a 4 m diameter drill bit and 3.3 m diameter casing. The shafts were then drilled under mud for stability, cased and cemented off. The method worked well, meeting all specifications within schedule and under budget.

Tunnelling in the limestone was a pleasant surprise. The planned zone was level and continuously competent, and no serious emissions were encountered. As can be seen in the pictures, the mine fully meets its objective as a safe, operable subway to the well-head.

The drilling of the process wells was perhaps the biggest challenge. Conventional oil rigs could not work in the confined space of the tunnels, and conventional underground drills were not capable of drilling and completing large diameter oil wells. A custom drilling rig was designed and built in Calgary to do the job. Since the wells were initially drilled upwards to reach the oil sands and then diverted to horizontal, new techniques and equipment had to be developed for drilling fluid pressure control, well surveys, logging, and running casing under pressure. The learning curve was very steep on this unique operation, but at the end of the day, the wells were successfully completed and a whole new drilling technology had been demonstrated.

Process:

The UTF exists to develop and demonstrate horizontal well in situ recovery processes, and it has already exceeded the most optimistic expectations. Two processes have been successfully demonstrated at the Phase A pre-pilot level of operation, either one of which represents a major breakthrough in in situ recovery from the Athabasca.

The challenge in the Athabasca is to cope with a highly variable reservoir containing the most viscous bitumen in Alberta which renders the formation essentially impermeable under reservoir conditions. Horizontal wells are proving to be the key to establishing controlled communication through the reservoir for effective heating and drainage of this bitumen.

Steam injection and oil production are controlled from the Phase A operations chamber in the limestone below the oil sands.

The prime process under test in the Phase A operations has been the steam-assisted gravity drainage (SAGD) process described earlier. Results from the field testing have been extremely encouraging, both in terms of absolute process performance and in the confirmation of the program design basis. Specific data are proprietary to the project participants, but the unscaled plots in the diagram below show clearly the excellent fit of actual results with the design plan.

The dashed lines noted as high and low forecasts were set as the expected envelope of

performance shortly before the field test was initiated. These forecasts came out of extensive reservoir engineering simulation work and were based on a judgment of the range of reservoir properties that might be encountered. The actual performance of the three well pairs testing the SAGD process is also plotted. The A1 pair experienced a difficult start-up, because of a particularly severe localized shale, but has since tracked the high performance slope closely. The A2 pair came on stream several months later, started up quickly and is now coping with formation conditions which are more

similar to the low forecast reservoir. The A3 pair start-up was considerably delayed because of shale and other testing; once established on the SAGD process, A3 production climbed rapidly. The results have been both very encouraging and better than initial theoretical predictions. The mathematical model used to predict the performance of the system has now been adjusted using these data, thereby making future predictions more reliable.

As a point of interest, more conservative forecasts made at the time of project commitment, before much of the detailed simulation work had been carried out, were considerably below even the low forecast in the diagram. In this light, the actual performance of the test well pairs has been a resounding success.

Field results on Chevron's HASDrive process are also exceeding forecasts.

In total, the Phase A level tests have confirmed the ability of horizontal wells to cope with the Athabasca challenge. Below-fracture steaming and gravity drainage can provide exceptional recovery with highly efficient steam use. Economics projections from these results show the clear possibility of viable commercial

operations at the UTF site.

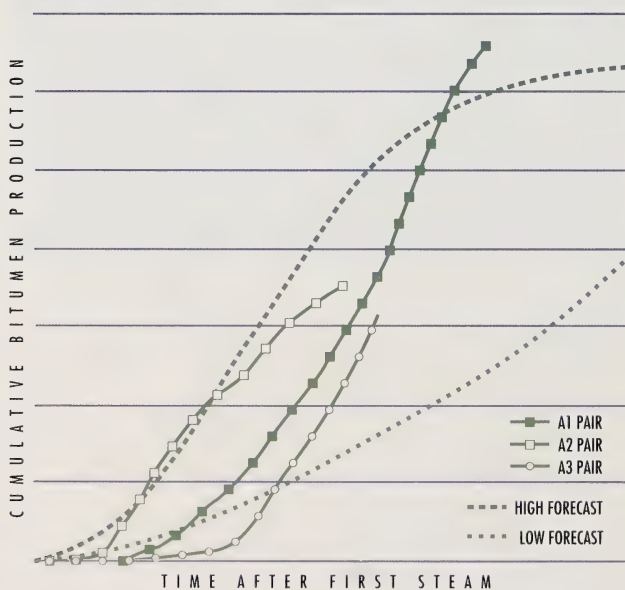
Organization:

Because of adverse industry conditions at the time, AOSTRA found itself in the unusual position of taking the initiative as operator in the development of the UTF project. The challenge of maintaining cooperative development with industry has also been met.

Early in the project, industry representatives joined in a consultive steering committee to work with AOSTRA in process evaluation and the planning of the field tests. This helped ensure industry concurrence with the overall program as it evolved. Later on, as conditions in the oil industry improved, several of these companies became participants in the process testing phase of the development. AOSTRA will continue to act as operator during the pilot programs, but the stage is set for eventual transfer to an industry operator if the program moves to commercial scale.

As operator, AOSTRA has executed the project on a contract basis making full use of Alberta resources. It has been very much a local success. The new technology has been developed by Albertans and is readily available to Alberta industry.

ACTUAL VERSUS PREDICTED CUMULATIVE BITUMEN



Excellent results from the Phase A tests provide confidence in the modelling techniques and incentive to advance further.



Driller at the controls of the underground drilling system developed in Alberta to meet the unique demands of the UTF horizontal wells.

FUTURE

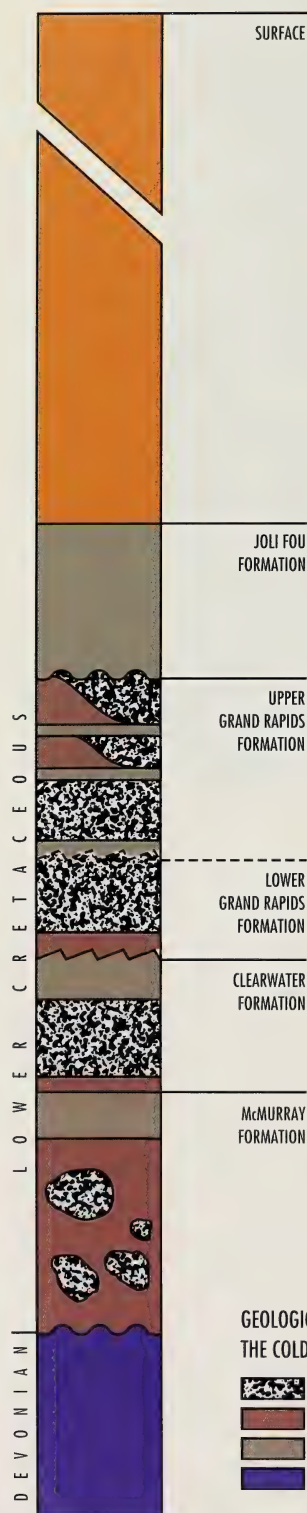
From the work to this point, AOSTRA is convinced that further pilot development at the UTF is fully warranted. The Phase A performance and the supporting economics studies show prospects for a commercially viable expansion operation under a wide range of expected product values. Confidence in these prospects would be greatly enhanced by the successful demonstration of Phase A performance at the long well Phase B level.

The Phase A level program now underway is scheduled to run until the end of March 1990. A program to expand the operation to the Phase B pilot level has been agreed to with the project participants. It will be based on the testing of three pairs of wells, each 600 m long with 500 m of completion in the oil sands. These pilot pairs will be similar to the proposed commercial well pair design and will represent a significant scale up of the 60 m completions employed in the Phase A test wells.

On the Phase B program schedule, the pilot wells and expanded process facilities should be in place early in 1991. Steaming will begin late that spring, and definitive results for the planning of any further expansion should be achieved by 1993.

Technology developed in the UTF will eventually have application well beyond the project itself. The near term future for the UTF technology is likely to be in the vast Athabasca oil sands which so far have defied profitable in situ

recovery. However, other applications can be seen over a much wider range, from heavy oil to conventional crudes, wherever difficult production situations can benefit from the unique properties of horizontal wells. It promises to be an especially effective technology, which, at the appropriate time, will play a major role in heavy oil development.



GEOLOGICAL SECTION FROM
THE COLD LAKE DEPOSIT

-  OIL SANDS
-  BARREN SAND
-  SHALE
-  LIMESTONE
-  & DOLOMITE

ALBERTA'S TOTAL IN-PLACE BITUMEN RESERVES AMOUNT TO 267 BILLION M³ (1.7 TRILLION BARRELS), ONE OF THE LARGEST HYDROCARBON RESOURCES IN THE WORLD. BITUMEN RESERVES IN THE COLD LAKE AREA AMOUNT TO 35 BILLION M³ (220 BILLION BARRELS) WHICH IS ABOUT 13 PERCENT OF ALBERTA'S TOTAL BITUMEN. WHILE TOO DEEP FOR SURFACE MINING, COLD LAKE BITUMEN RESERVES HAVE BEEN SUCCESSFULLY PRODUCED USING IN SITU THERMAL RECOVERY METHODS.



Field piloting of thermal recovery methods in the Cold Lake area began in the early 1960's, well before the creation of AOSTRA. By the time AOSTRA was formed in 1975, field piloting of thermal recovery processes was well advanced in some areas of the formation. In 1988, commercial projects developed in the Cold Lake and Lindbergh area produced 5.6 million m³ bitumen with the majority of production (4.7 million m³) from commercial projects developed within the Clearwater formation in the Cold Lake area using thermal techniques. To date only 1.8 billion m³ of reserves have been subjected to commercial development out of the potential 35 billion m³ of initial bitumen in place. This represents development of only 5 percent of the total resource to date.



Recovery factors for commercial projects within the Cold Lake bitumen reserve area are about 15-20 percent. The highest recovery is expected to be achieved from projects in the Clearwater formation. As a result, an exciting opportunity exists not only to find methods of recovery that are applicable to the undeveloped reserves in the Cold Lake area, but also to improve the percentage recovery from existing developed projects. This is one of the many challenges that was faced by industry and AOSTRA since the latter's formation in 1975.



RECOVERY METHODS

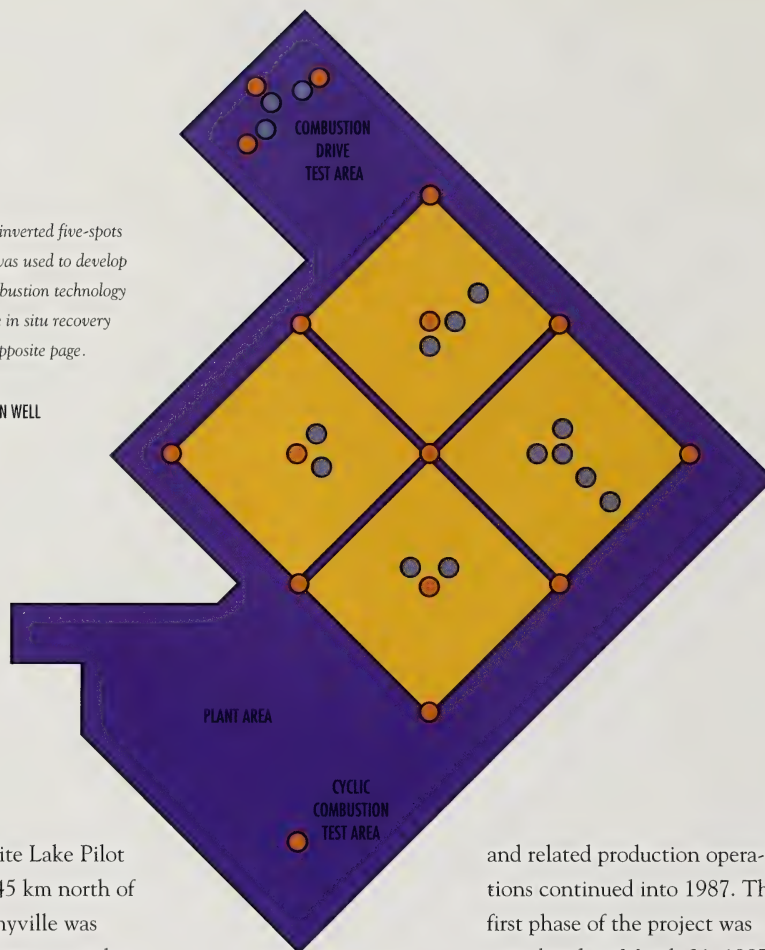
The recovery procedure used in the Cold Lake area for commercial production is cyclic steaming or the “huff and puff” method. The method is simple, effective, and economic in thick, rich oil sands such as parts of the Clearwater formation in the Cold Lake area. However, the ultimate recovery of oil in place using this method in the best parts of the formation is about 20 percent.

The major technical challenges in the area are to find methods that will improve the ultimate recovery of bitumen in the thicker, rich formations and methods of producing the thinner formation in an economic manner.



Commercial scale steam huff and puff operations are ongoing in the Cold Lake oil sands.

A well pattern of four inverted five-spots plus special test wells was used to develop steam and oxygen combustion technology at the Marguerite Lake in situ recovery pilot, pictured on the opposite page.



The Marguerite Lake Pilot Project, located 45 km north of the town of Bonnyville was designed to test steam stimulation followed by wet combustion in the Clearwater sand formation of the Cold Lake oil sands deposit. BP Exploration Canada Limited operated the project with AOSTRA, Dome Petroleum (now Amoco), and PanCanadian Petroleum Limited as participants.

The project was started in 1978 and completed an initial steam stimulation phase and simultaneous combustion testing with air in special test wells. The decision to use oxygen instead of air for the combustion phase was made based upon feasibility studies

conducted after the initial test phase. The project consisted of 16 producing wells, five injection wells, and a number of observation wells in the main pilot area. There were three combustion drive wells, a "burn and turn" (combustion followed by production) well, and two observation wells outside the pattern. These wells were used to test the combustion process using air.

The five injection wells in the main pattern were converted to oxygen injection. Encouraging results were obtained with oxygen injection

and related production operations continued into 1987. The first phase of the project was completed on March 31, 1987, and an extension phase, in which AOSTRA did not participate, is being conducted by BP. The project demonstrated that oxygen could safely and effectively be utilized in a combustion phase following cyclic steam injection to increase ultimate oil recovery. A summary report on the first phase of the project is under preparation.

The Wolf Lake project, which surrounds the original pilot project area, started production in April 1985, based on steam technology

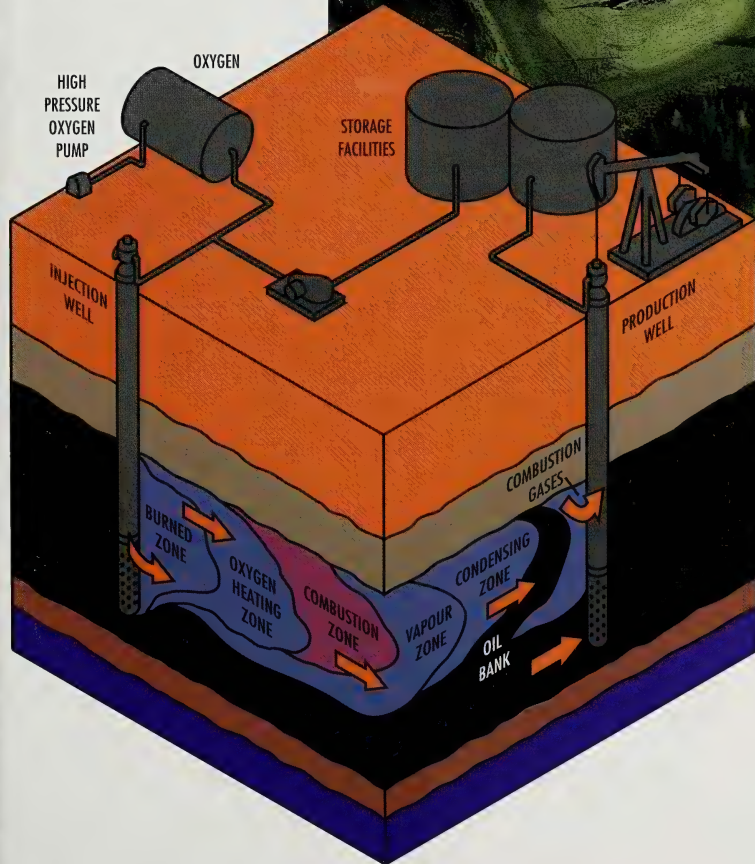
developed at the Marguerite Lake pilot. BP is planning to use the oxygen combustion technology in the Wolf Lake operation.

A second project was initiated in the Lower Grand Rapids formation in the Cold Lake area to evaluate recovery by steam stimulation. The Lower Grand Rapids formation contains reserves equivalent to the Clearwater formation in the Cold Lake area. The Lower Grand Rapids formation, while not as rich or as thick as the Clearwater formation, contains a large untapped bitumen reserve.

The pilot project, called the "B-Unit," was operated by BP Exploration Ltd. with AOSTRA and Petro-Canada as participants. The B-Unit was a single well cyclic stimulation project with two observation wells in the Lower Grand Rapids formation. The producing zone is 16 m thick at a depth of 430 m. The objective of the pilot testing was to improve bitumen recovery by novel fracturing/injection methods which were developed at the AOSTRA - BP Marguerite Lake pilot located 10 km to the north.

The pilot was initiated in 1982. Four cyclic steam injections were performed on the injector over a three and a half year period. A significant volume of bitumen was produced at low steam-oil ratios and attractive production rates.

Based upon the encouraging results of the single well B-Unit test pilot, BP and Petro-Canada drilled 22 wells from a single pad for production from the Lower Grand Rapids formation at a location adjacent to the Wolf Lake operations. Steam stimulation operations have commenced on this project.



PRESSURE CYCLE OXYGEN FIRE FLOODING

This pressure-up/blow-down oxygen process is a follow-up to cyclic steam stimulation. During the pressure-up phase, oxygen and water are injected into the reservoir where combustion heats previously unrecovered areas. Oxygen injection is then terminated and mobilized bitumen is produced in the blow-down phase. This sequence is repeated a number of times.

Cluster drilling of deviated wells was used at the AOSTRA/Bow Valley Cold Lake pilot to reduce environmental impact and improve economics.

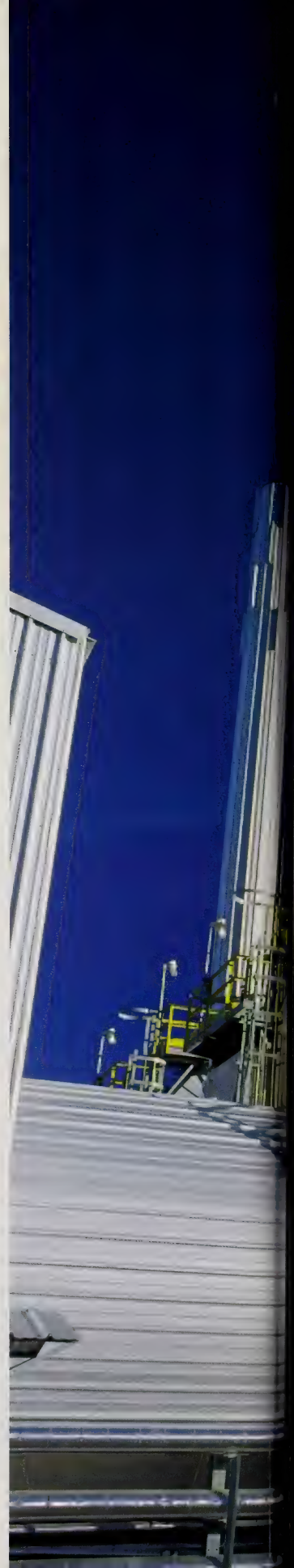


A significant amount of bitumen is contained in thinner zones in the Clearwater formation in the Cold Lake area. While commercial operations have commenced in the thicker and more attractive zones, the technology to develop the thinner zones is now being developed. Bow Valley Industries operates a pilot called Marie Lake in the Cold Lake area in which AOSTRA is a participant. The pilot was designed to test the use of superheated steam plus carbon dioxide and a clay stabilization additive for recovery of bitumen from the Clearwater formation. The average pay thickness of the zone is 12 m and is located at a depth of 420 m. The pilot is located 25 km north of the town of Grand Centre.

A preliminary laboratory study and field study indicated that the proposed process had technical merit. Pilot operations using a modified recovery process were started in an inverted seven-spot pattern in 1984. The pilot results were encouraging and a second inverted seven-spot pattern on larger spacing plus two special wells were drilled in 1986. The operation of both patterns plus the special test wells are still currently underway.

Plans have been drawn up for the development and implementation of a pre-commercial pilot phase consisting of an 18-well expansion. Drilling operations on this phase are expected to commence in early 1990.

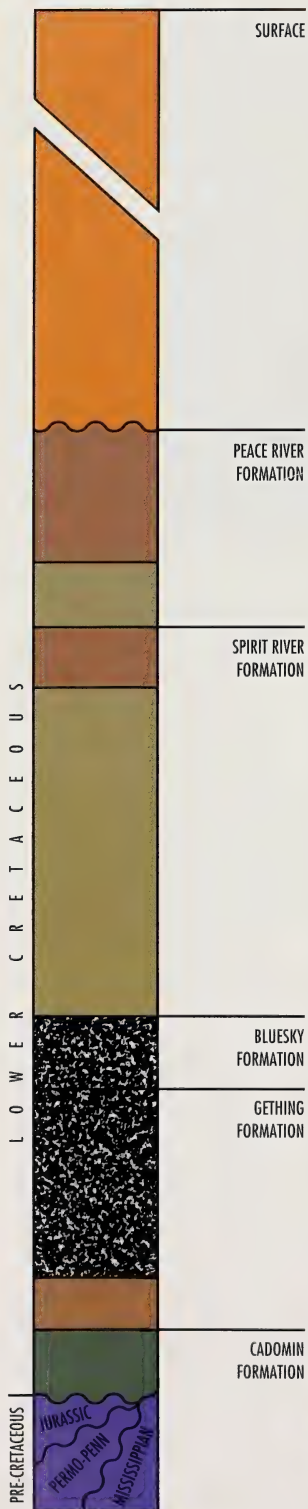
In addition to the field piloting work described above, AOSTRA has been involved in cooperative studies with industry to determine if the new technology can be applied to different reservoirs. AOSTRA, Suncor, and Canadian Worldwide Energy Limited conducted a study which was completed in 1986 on the potential use of steam additives to improve oil recovery at the Suncor Fort Kent commercial demonstration project in the Cold Lake area. The combined engineering feasibility study evaluated the patented steam plus carbon dioxide and naphtha additive process developed by AOSTRA at the Alberta Research Council. The study indicated that additional recovery could be achieved with the steam additive system. However, improved oil prices would be required to make the process economically attractive.





AOSTRA's support of field pilot projects in the Cold Lake area has been fruitful. One of the projects, the BP Marguerite Lake project, led to the development of the BP/Petro-Canada Wolf Lake commercial project. The BP B-Unit project led to the development of a large multi-well operation in the Lower Grand Rapids formation. The Bow Valley Marie Lake project is being expanded to a pre-commercial phase. AOSTRA's efforts with its partners in the Cold Lake area have accelerated the creation of technology to produce this large and difficult reserve.

Efficient steam production provided by boilers fired with clean Alberta natural gas is a key element in commercial in situ bitumen production for the Cold Lake oil sands.



THE PEACE RIVER OIL SANDS DEPOSIT IS THE THIRD LARGEST IN ALBERTA. ON THE SHELL LEASE ALONE, SHELL ESTIMATES THERE IS ENOUGH RECOVERABLE BITUMEN TO PRODUCE 100,000 BARRELS A DAY FOR OVER 100 YEARS.



The viscosity and the depth of the deposit make it more comparable to the Cold Lake deposit than the Athabasca deposit. An important feature of the Peace River deposit is the extensive area of thick rich oil sands, underlain by a thin water-sand layer, which permits very effective steam injection without fracturing the reservoir.

In 1974 when AOSTRA was formed, development of the Peace River oil sands deposit was at an early stage. Shell had discovered the deposit in the 1950's and conducted three very small pilot projects in the 1960's with inconclusive results. A single-cycle injectivity test in one well was conducted in 1973/74. High steam injection rates were achieved without fracturing, and production response was excellent. This 1973/74 test, in conjunction with an extensive program of scaled physical model experiments, resulted in the development of the pressure cycle steam drive recovery process.

Although the results obtained by Shell were encouraging, it was necessary to test the recovery process with a

large pilot, to obtain results which could be scaled up directly to a commercial operation. However, as Shell has reported, "It gathered dust until the late seventies, when the province formed AOSTRA. That was the catalyst which got the project going in earnest. It was the first project in which AOSTRA was a partner which has led to commercial exploitation of the tar sands."



The new pilot operation was called PRISP (Peace River In Situ Pilot), in which AOSTRA participated until 1985. It was a bold venture, with 31 wells arranged in 7 seven-spot patterns. Each pattern contained a steam injection well at the centre surrounded by production wells, with an interwell separation of 100 m.



The AO/STRA/Shell PRISP pilot in the Peace River oil sands has been called the lucky "7" pilot because the pilot pattern is 7 seven-spot patterns, each of 7 acres size.



PRESSURE CYCLE STEAM DRIVE

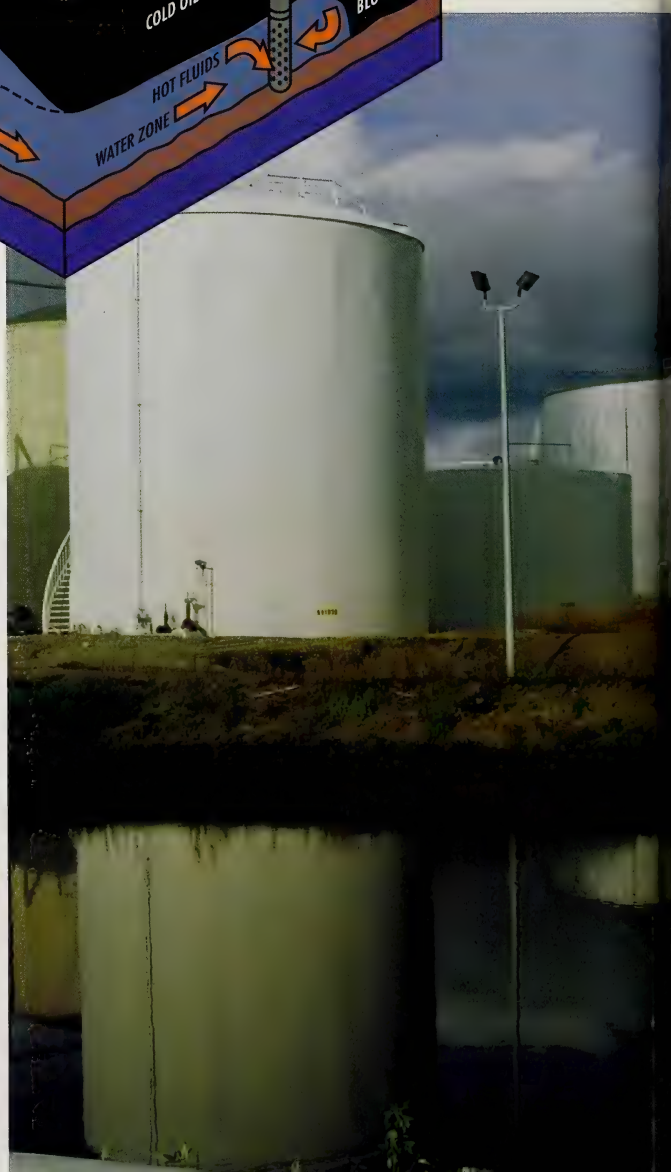
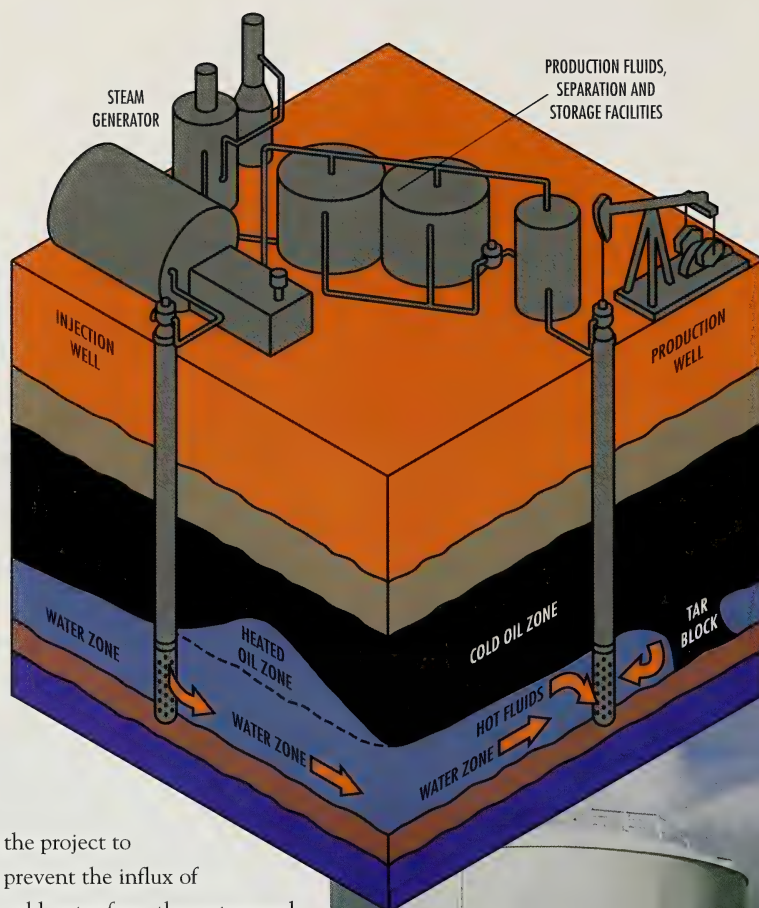
A steam drive process with pressure cycles. Steam is injected into the reservoir without fracturing via underlying water sand which is permeable to the steam. This results in a radial heated zone at the base of the reservoir and mobilizes the overlying bitumen.

The recovery process utilizes the water-sand layer at the base of the formation to provide the required fluid injectivity, since the rich oil sands layer is completely impermeable at initial reservoir temperature. This basal water-sand provides an excellent means to distribute heat radially through the reservoir, and to heat the rich bitumen zone from below so it can be efficiently recovered by means of gravity drainage. This process is generally preferable to the use of high pressure fractures, which are typically required in the Cold Lake deposit, because fractures are difficult to control and usually create long, thin, linear heated paths.

The steam drive pressure cycle has several steps. Initially each well undergoes cyclic stimulation in special sequences to create hot communication paths between wells, and to create tar banks surrounding

the project to prevent the influx of cold water from the water-sand outside the project boundary. Continuous steam injection is then begun with the injection and production rates so controlled as to alternately pressure-up and blow-down the reservoir. Three and a half of these pressure cycles have been conducted in the PRISP pilot to date, with each cycle lasting about two and a half years.

The performance of the PRISP pilot has met all expectations, producing approximately 3.5 million barrels of bitumen over a period of ten years. The performance of PRISP is comparable to that of Alberta's best oil sands project,



namely Esso's Cold Lake pilot, which is in an exceptionally rich deposit. The PRISP pilot has an oil production rate somewhat below that of the Esso pilot, and a steam-oil ratio which is slightly higher. However, the offsetting advantage is that the well life in PRISP is longer. The PRISP pilot has particularly excelled in recovery efficiency, already achiev-

ing close to the expected recovery of 55% of the oil-in-place. This should be compared to a typical recovery efficiency of only about 15-20% for the Cold Lake deposit.

In 1983, the Multi-soak pilot was installed adjacent to the PRISP pilot whereby cyclic steam injection was tested in four wells. The principal purpose of this test was to

determine whether individual well steam cycles prior to steam drive in patterns would improve the early pilot performance. The results of this pilot were excellent, with higher oil rates and the same steam-oil ratio as that reported for Esso's Cold Lake pilot, although it was over a shorter time span. The wells were still performing very well after

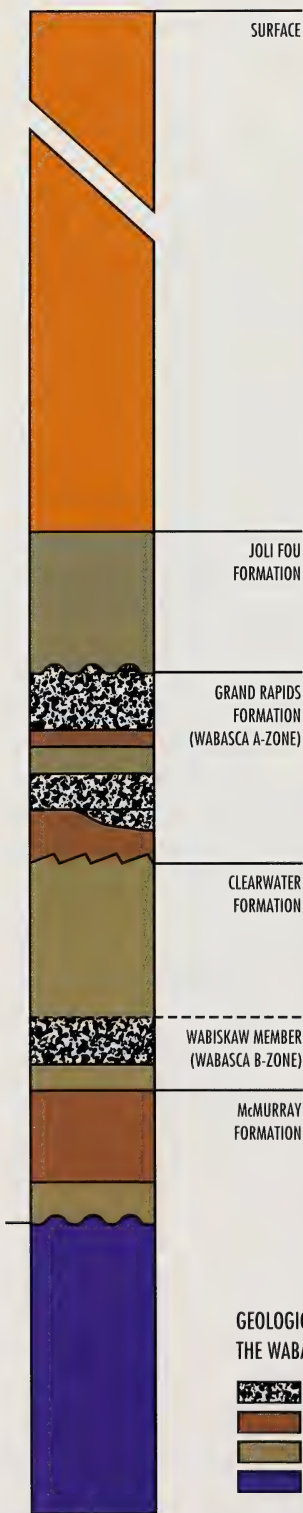
three cycles in four years when they were incorporated into the commercial project.

From the success of the PRISP pilot, Shell proceeded directly into commercial operations with the PREP (Peace River Expansion Project) facility, which began operations in 1986. The first phase of PREP includes 212 wells, arranged in four clusters, each containing 13 patterns which are generally identical to those in the PRISP pilot. Three such phases of operation are planned which will operate for a total of 30 years. The performance of PREP to date has followed predictions very well and has reached its target of 10,000 barrels per day.

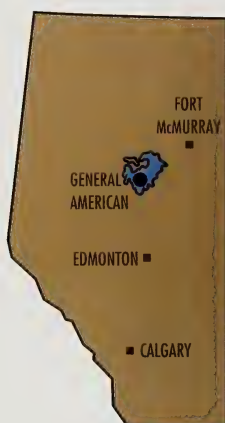
Despite the commercial success of the Peace River program, AOSTRA is continuing to work towards improving the existing recovery process so it can be applied economically to less favourable reservoirs. This includes studies toward better utilization of cyclic stimulation, and the use of horizontal wells which offer the promise of another major step forward in recovery performance.



Production storage tanks at Shell's Peace River operation.



THE WABASCA OIL SANDS ARE THE SMALLEST OF THE OIL SANDS DEPOSITS IN ALBERTA WITH LESS THAN 5% OF THE TOTAL OIL SANDS BITUMEN. ALTHOUGH THE WABASCA (SOMETIMES DESIGNATED AS SOUTH ATHABASCA) IS THE SMALLEST, IT STILL CONTAINS OIL IN PLACE ABOUT EQUAL TO THE TOTAL LIGHT OIL IN ALBERTA.



The Wabasca oil sands pose difficulties for the in situ recovery of bitumen. The deposits are in thin zones with the bitumen as viscous as that in the Athabasca oil sands. In addition, the Wabasca oil sands are at relatively shallow depths of about 225 m for the A-zone and about 350 m for the B-zone. These shallow depths restrict the maximum pressure and thus the temperature to which the reservoir can be subjected during thermal recovery operations.



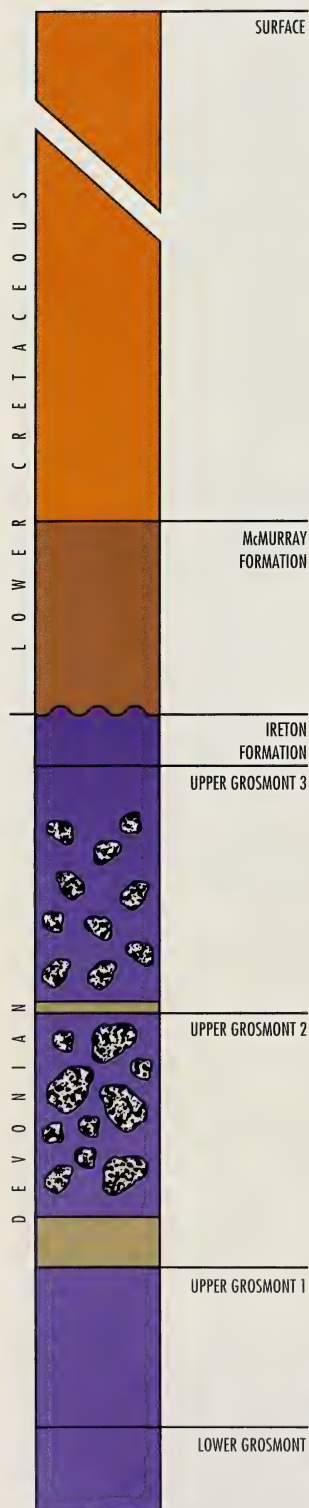
Grand Rapids Formation type outcrop at Grand Rapids on the Athabasca River. In the subsurface, these rocks are bitumen impregnated and form the Wabasca A Deposit.

When AOSTRA began in 1974, there had been some unsuccessful attempts to recover bitumen from the upper Wabasca A-zone by both steam and combustion methods. AOSTRA chose not to participate in these ongoing activities in 1974 because of the difficult problems faced in Wabasca for in situ recovery. However, in 1982, AOSTRA joined General American in a pilot project aimed at using forward in situ combustion drive to recover bitumen from the deeper but thinner B-zone. Single well tests were also run using the steam huff and puff method in the same zone which gave promising but sub-commercial results. The in situ combustion pilot did not yield commercial results and was terminated. However, careful analysis of the pilot data, the steam huff and puff results, and surrounding geological core wells gave a surprising result: the viscosity of the bitumen in the Wabasca B-zone is highly variable. The viscosity varied from the high viscosity Athabasca-like bitumen to oil with viscosity equivalent to heavy oil and capable of potential primary production.

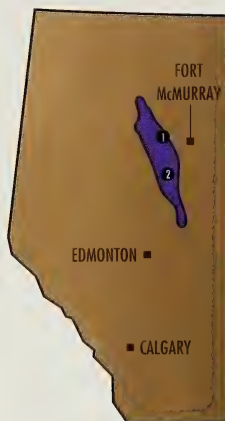
Over the subsequent years, pilot operations in the Wabasca have concentrated on the Wabasca B-zone using in situ combustion. The most recent development in the Wabasca area is the use of horizontal wells for production of heavy oil from those areas of the deposit which have the lower viscosity heavy oil capable of primary production. The commerciality of the production is hampered by the thinness of the Wabasca B-zone and by producing problems associated with horizontal wells. Progress in the Wabasca oil sands has been difficult and challenging. A future commercial production scenario is possible in the area, based on recovery of the lower viscosity heavy oils. A barrier to this scenario is an adequate understanding of the extent and location of the heavy oil area among the bituminous oil sands in Wabasca. It is likely that the technology associated with horizontal well operations will improve in the coming years which could lead to lower costs and higher recovery for the oil.

In situ combustion was tested for recovery of bitumen from the Wabasca oil sands at the Joli Fou pilot plant operated by General American Oil Ltd.





THE GROS MONT CARBONATE FORMATION IN NORTH CENTRAL ALBERTA COVERS AN AREA ABOUT THE SIZE OF HAWAII. CONTAINED IN THE FORMATION IS A VOLUME OF BITUMEN IN PLACE COMPARABLE TO THE HUGE ATHABASCA OIL SANDS DEPOSIT.



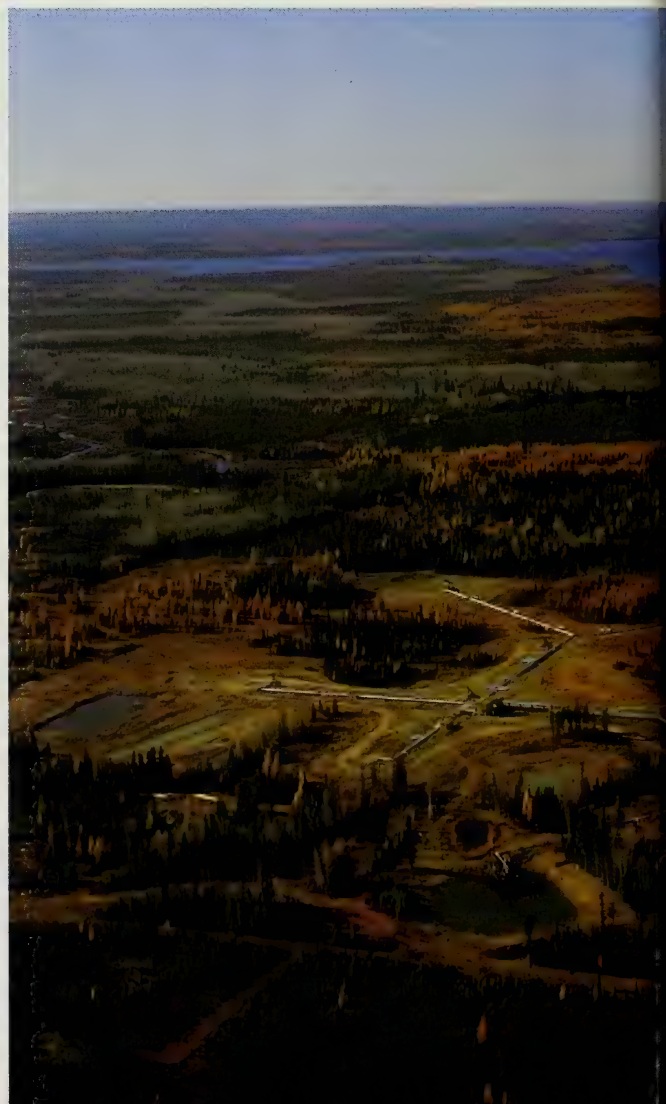
1 UNOCAL
2 CHEVRON

GEOLOGICAL SECTION FROM THE GROS MONT CARBONATE

-  OIL SANDS
-  BARREN SAND
-  SHALE
-  LIMESTONE & DOLOMITE

The carbonate has a dual porosity system with part of the bitumen contained in variable-sized tunnels or vugs, in the formation, interconnected by fractures, together with bitumen in crys-

talline carbonate of varying grain size. The bitumen in the Grosmont is heavier than Athabasca bitumen and is so dense that it will not float on water. The irregular tunnels vary in size up to that of a man's arm and sometimes much larger. When drilling wells, the drill bit has been observed to drop several feet as it passed through a large tunnel filled with bitumen. The drilling and completing of thermal in situ



injection and production wells in the Grosmont Carbonate are a real challenge. The irregular tunnels in the formation lead to a loss of mud circulation during drilling. The placement of cement to maintain a strong well-to-formation bond is difficult under those conditions present in the Grosmont Carbonate. The most promising area in the Grosmont Carbonate is to be found in a part of Alberta

which is largely undeveloped. There is no permanent road into the area. Access is by air in summer or by a 75 km winter road in the cold months. The main, potentially productive zones in the Grosmont are called the Upper Grosmont 2 and Upper Grosmont 3 zones. These zones are at a depth of about 280 m with a combined average thickness of 70 to 90 m.

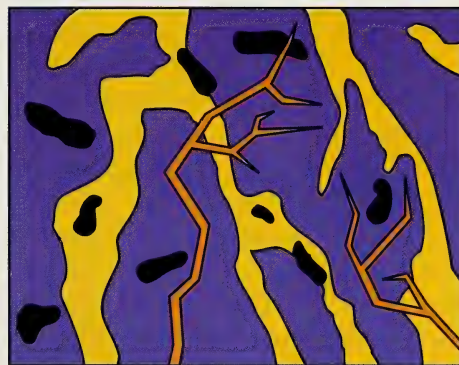
When AOSTRA was formed in 1974, the Grosmont

Carbonate represented a huge potential resource about which very little was known in terms of in situ recovery potential. Prior to AOSTRA becoming involved in field pilot work, Unocal and Canadian Superior conducted a series of field tests in the Grosmont Carbonate to assess steam stimulation, steam drive, and combustion as potential methods for in situ recovery. These trials were of limited duration and scope

because of the isolated area, but the results were spectacular. Bitumen production rates from a single steam stimulation well of up to 87 m³ per day (550 barrels per day) were obtained.

AOSTRA joined Unocal and Canadian Superior in 1979 in a program of field pilot investigations aimed at the development of in situ recovery methods based on steam stimulation and steam drive technology. The first step in this technology development program was the construction of the Buffalo Creek 10A Pilot.

DUAL POROSITY SYSTEM OF THE GROSOMT CARBONATE



Bitumen is contained in vuggy "tunnels" up to several centimetres in diameter in the Grosmont Carbonate formation. At the Buffalo Creek and McLean steam based in situ pilots, shown in the aerial view, spectacular but erratic bitumen recovery rates were achieved.



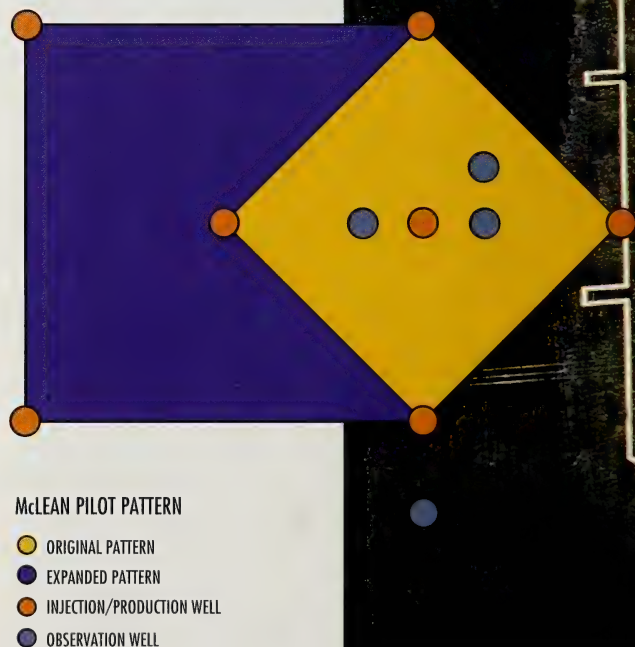
The Buffalo Creek 10A program was designed as a single-well steam stimulation pilot in the Grosmont 2 zone. The well site was located close to existing steam and production facilities but far enough from previous test wells to avoid interference. To monitor heat propagation and the sweep efficiency of the steam, four temperature observation wells were installed at various distances around the single injection/production well. The Buffalo Creek 10A proved to be a very successful operation which ran from startup in early 1980 through to 1986. The well showed very high production rates of up to 70 m³ per day of bitumen (440 barrels per day). While the pilot produced a great deal of bitumen, the isolated area and the lack of an all-weather road, prevented the produced bitumen from being marketed. The bitumen and produced water were re-injected into an offsetting disposal well after measurement of the production volumes.

The excellent bitumen production from the Buffalo Creek 10A pilot prompted expansion to a multi-well pattern called the McLean pilot. Sites were considered in the vicinity of the 10A pilot, relatively close to the upper Grosmont erosional edge. Four seismic lines were shot in 1981, in an area

about 3 km south of the pilot. On the basis of this survey, the site of the 2.42-hectare McLean pattern was finalized. A five-spot pattern was used, with the corner injectors/producers spaced 110 m from the centre well. The pilot spacing was selected on the basis of recovering 50% of the oil within the pilot in 2.5-3.0 years. There were three observation wells within the pattern and one south of the pattern.

The recovery strategy planned for the McLean pilot was steam drive from the central injection well, following stimulation of the surrounding producers. The small pilot pattern size was chosen in order that early steam drive results could be obtained. Early and rapid results were favoured in order to speed technology development and also to reduce costs. The isolated conditions at the Grosmont Carbonate pilot site, doubled to tripled the cost of conducting the pilot operations, and the bitumen produced could not be economically marketed to offset costs. Because the volume of bitumen produced by the multi-well pilot made re-injection of the produced bitumen difficult, the material from the multi-well pilot was collected in a surface containment reservoir during the summer then heated with steam coils in the winter, pumped onto trucks and transported over the winter road to market.

The Grosmont Carbonate formation is highly variable over short distances. The initial operations in 1983 in the McLean pilot indicated a geological anomaly within the pilot area which was of a nature which reduced the value of the pilot for general testing of the steam drive recovery concept. The anomaly was a region with linking tunnels between the Grosmont 2 and Grosmont 3 zones which prevented good pressure and steam containment within the pilot pattern.





A winter road is the only surface access to the Buffalo Creek in situ pilot in the Grosmont Carbonate area. During the summer, all supplies and personnel must be moved in and out by airplane because of the impassable muskeg conditions. The isolated location doubles the cost of pilot operations.

In order to put into practice the initial pilot concept, two additional wells were drilled in 1984 to produce a new and larger five-spot pattern to the east of the original McLean pilot. The results of both pilot patterns were not as successful as anticipated, owing to premature breakthrough of steam channels among the central injection and production wells. In 1985 a new single well was drilled at a location offsetting the McLean pilot. The well was produced with cyclic steam stimulation. In 1986 a special test program was conducted to investigate the relationship of the unusual geology to well operation in the McLean pilot. Because of the conflicting results of the 1986 field program, the field operations were suspended and data analysis continued through 1987 and 1988.

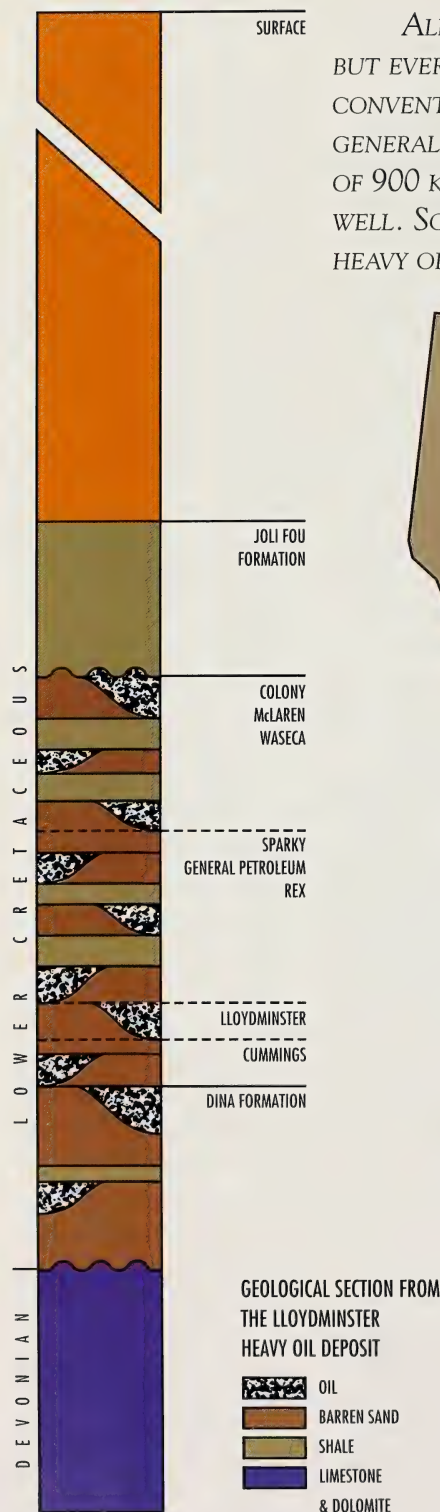
The only other thermal recovery operation in the vast Grosmont Carbonate area was a single well, steam stimulation test conducted by AOSTRA and Chevron Canada Re-

sources in the Algar area in the Grosmont in 1985. The results of the test were not encouraging due to the presence of a gas zone close to the bitumen region.

The future of the Grosmont Carbonate for bitumen recovery is potentially very great. The pilot operations to date have produced hard-won and costly results which are of great value in setting the course for future technology development. Three main issues must be faced in determining the direction of development for bitumen recovery in the Grosmont. These are:

1. the relation of Carbonate reservoir type to the recovery results;
2. high pilot costs arising from a lack of permanent roads and other facilities;
3. a strategy for operation of multi-well systems in the Carbonate setting;

The issues above suggest that a consortium effort by interested parties may be necessary to move the technology development forward. AOSTRA is currently giving serious consideration to the concept of a consortium and is currently having discussions along these lines with individual companies.



ALBERTA'S HEAVY OIL RESERVES ARE A SMALL BUT EVER INCREASING COMPONENT OF ALBERTA'S CONVENTIONAL OIL PRODUCTION. HEAVY OIL IS GENERALLY DEFINED AS THAT OIL WITH A DENSITY OF 900 KG/M³ OR GREATER THAT WILL FLOW IN A WELL. SOME OF ALBERTA'S OLDEST FIELDS ARE HEAVY OIL PRODUCERS, E.G., LLOYDMINSTER.



- 1 PETRO-CANADA
- 2 NORCEN
- 3 AEC
- 4 PANCANADIAN

However, owing to a limited demand for heavy oil caused, in part, by the overwhelming supply of light and medium density conventional oils, the heavy oil industry grew slowly in Alberta. With the recent decline in light and medium oil production, the development of heavy oil upgraders, and the increasing demand for heavy oils, this industry has seen rapid growth in the last few years.

As of year end 1988, a total of 1.4 billion m³ (8.6 billion barrels) of heavy oil had been discovered in Alberta. The average oil recovery by pools producing by primary depletion is 7 percent. For pools producing under waterflood, the average recovery factor is 29 percent. Waterflooding has been applied to only 19 percent of the heavy oil reserves in Alberta, and the average heavy oil recovery factor will be 11 percent based upon the present recovery methods in operation within the heavy oil pools.

Applying this recovery factor of 11 percent, Alberta's initial total established reserves of heavy oil are 157 million m³. Cumulative heavy oil production to date has been 104 million m³ leaving 53 million m³ of remaining established reserves. At the current heavy oil production rate of 8.4 million m³ per year, Alberta's heavy oil life index is about six years.

Alberta's heavy oil reserves measured by original oil in place are equal to about 17 percent of Alberta's conventional oil reserves. Because of the lower average recovery factor in heavy oil reservoirs, the remaining established reserves of heavy oil amount to about 9 percent of total remaining Alberta conventional oil reserves.

Nevertheless, the 89 percent or 1.2 billion m³ (7.6 billion barrels) of presently unrecoverable heavy oil are an economically attractive challenge for recovery enhancement. To date, waterflooding on a limited scale has been the major enhanced recovery process applied to heavy oil pools. Because of technical problems, waterflooding cannot be universally applied to heavy oil pools and other methods must be used to improve recovery.

Produced heavy oil and water are separated in heater/treaters at the AEC operated SHOP project.

PROGRESS IN HEAVY OIL RECOVERY

In 1978, AO STRA joined Petro-Canada (then Pacific Petroleum Limited) in a jointly funded heavy oil project designed to compare the results of two recovery methods being tested in the same pool. The first method was a steamflood to drive oil to adjacent producing wells, and the second was combustion by air injection to heat the reservoir by burning part of the oil. The project was located 80 km southwest of Lloydminster. Specifically, the objective of the project was to evaluate and compare the performance of steamflood and fireflood in Lloydminster-type thin reservoirs. The producing region was a 5 m pay zone in the Sparky formation located at a depth of 680 m.

Two five-spot patterns were drilled in separate areas of the reservoir. Data from previous drilling records indicated that the reservoir was continuous. However, one pattern was truncated by an unmapped silty channel. The air injection combustion pattern could be operated as planned, but the steam drive test had to be modified to take into account the geological channel.



Operation of the steam pattern was terminated in 1981 due to the geological problems and generally unsatisfactory performance. Air injection tests were hampered by corrosion problems in the injection wells. Three new production wells were drilled in 1982 within the combustion pattern to form two inverted contiguous five-spot patterns on reduced spacing. Wet combustion commenced in 1983 with early indications of oil produc-

tion response at the producing wells. However, hot well operational problems coupled with declining oil production led to the decision to terminate the project at the end of 1985. While the pilot was itself unsuccessful, a substantial amount of useful information was obtained and reported in a final summary report.

In 1980, Alberta Energy Company Limited, as operator, and AO STRA, Westcoast

Petroleum Ltd., and Muskateer Energy Ltd. (now Amoco Canada Limited), initiated a combustion project at Suffield, Alberta to determine whether combustion methods could be used to produce heavy oil from a reservoir with underlying water. There are numerous reservoirs of this type in southeastern Alberta and their primary recovery rates are often only marginally economic because of water breakthrough and a resulting oil production decline.

The reservoir at Suffield is a Glauconitic Sandstone 20 m thick at a depth of 900 m. The test pilot involved a single five-spot pattern covering 2 hectares. Combustion was initiated by the injection of air into the central well in 1982. Early in the life of the project, following air injection, it was noted that water production was substantially lower than forecast and the tendency for wells to "water-cone" early in the well life was not evident in the pilot wells. Although pilot production was significantly greater than would be expected by primary recovery alone, the combustion operation was suspended in 1986. However, the combustion project sug-

gested that suppression of the water production may have been caused by gas injection. This unexpected observation warranted investigation.

During 1986, a single well gas injection test was conducted in a production well directly offsetting the combustion pilot. The results of the gas injection test were encouraging. As a consequence, additional field testing of the gas injection technique was carried out in an inverted seven-spot pattern, plus 20 special single well tests at locations removed from the original combustion test pattern. Testing of the process was completed by year end 1988.

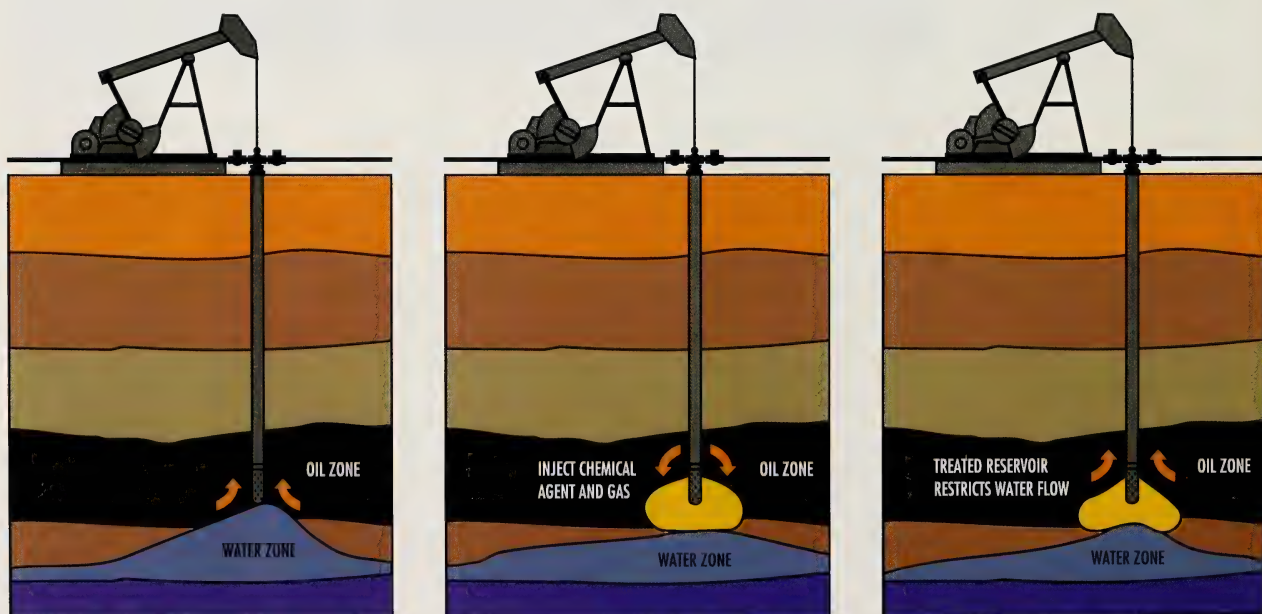
As a result of the numerous gas injection tests, AOSTRA's Anti-Water-Coning Technology (AWACT) was developed. A presentation of the technology was made to industry in June 1989. The meeting was attended by over 200 people. The AWACT technology was offered to industry under a licensing arrangement. Since the meeting in June, over 50 companies have expressed an interest in applying the technology in their operations where wells are exhibiting low oil productivity and high water production.

The AWACT technology is being actively marketed and testing is being encouraged in a variety of different pools.

In 1989, a hot water flood was put in operation in the Suffield project in an inverted four-spot pattern. The facilities are operated by Alberta Energy Company Limited with AOSTRA and Westcoast Petroleum Limited as participants. The injection of hot water was started in mid-1989 and will continue through 1990. This novel recovery technique was identified as promising for improving oil recovery from heavy oil pools underlain by water.

ANTI-WATER-CONING PROCESS

Water-coning into production wells is suppressed by periodic stimulation with injections of a non-condensable gas plus a chemical agent, introduced directly or via a central injector. The technique increases oil recovery and reduces the proportion of water produced.





In 1982, a wet combustion recovery project was initiated in the waterflooded Countess Upper Mannville "B" pool which is located 20 km west of Brooks, Alberta. PanCanadian Petroleum Limited, as operator, and LL&E Canada Limited are participants in the project. The pilot consists of a 16 hectare inverted five-spot pattern and associated surface facilities. The pool contains medium gravity oil of 28°API at a depth of 1066 m with a pay zone of 8 m.

PanCanadian is operating and financing the field pilot with LL&E. AOSTRA is funding a research program to support the pilot activities with the field and research results being shared among the parties. AOSTRA is the owner of and licensing agent for the technology being developed both in the field and in the research program.

Field pilot combustion operations are very encouraging with oil production rates greater than expected under continued waterflood operations. PanCanadian is planning to add two more air injection wells in two additional patterns in 1990 to further test the process.

The research program included coring of a well behind the combustion front to evaluate the efficiency of the reservoir combustion recovery process. In addition to the post-combustion core test, the supporting research program included combustion tube tests, emulsion treating studies, corrosion studies, combustion front mapping, numerical simulation modelling, the drilling of a sampling well for fluid sampling near the combustion front, and core flow tests to evaluate the recovery process.



Production storage and well drilling associated with PanCanadian's Countess "B" Pool in situ combustion pilot.

The positive results from the combustion project have encouraged PanCanadian to expand the pilot operations into a pre-commercial phase.

Norcen Energy Resources Limited is testing the use of steam for in situ recovery of heavy oil from the Bodo field in east central Alberta.



In 1987, a joint project was initiated by AOSTRA and Norcen Energy which involved laboratory studies on the comparison of steamflooding versus combustion in the Bodo field. Norcen and its partners, Canadian Cities Services Ltd. (now Canadian Occidental), Canadian Reserve Oil and Gas Company (now Tenneco Canada), and Murphy Oil Company Limited, were conducting a combustion project in the Bodo pool. This is a low gravity pool (13.5°API) producing from the Mannville "B" sand formation at a depth of 735 m. The project is located directly east of Red Deer near the Alberta-Saskatchewan border. The laboratory studies were encouraging and indicated that steam flooding was also feasible in the Bodo pool. Drilling of wells for a nine-spot steam pilot offsetting the combustion operations in the Bodo field began in late 1984 and

production operations in the steam pilot commenced in 1985. Four cycles of steam injection were completed in the wells by mid-1989 when the nine-spot pattern was converted to a steamflood by continuous steam injection into the central injector. Steamflooding operations continued into 1990.

In response to a need by industry, AOSTRA and nine oil companies entered into an agreement in 1979 to conduct a review of problems involved in lifting or pumping fluid from heavy oil wells. This review was conducted by Pengalta Research and Development. The first phase of the project consisted of a determination of the state-of-the-art and a definition of the problems encountered. This led to the development of Phase II which involved the establishment of experimental facilities to develop solutions for the problems identified in Phase I. There were originally ten participants in Phase I; this grew to fourteen participants in

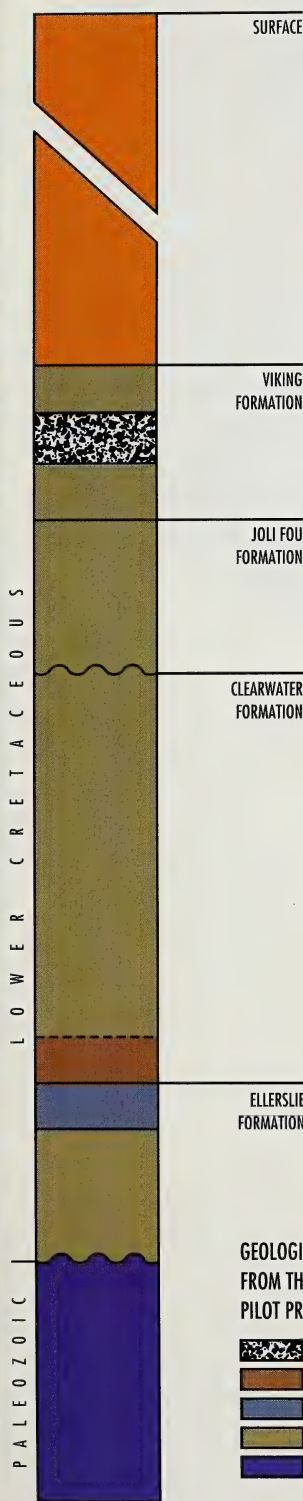
Phase II. Several innovative pump designs were examined and some were selected for field testing in Phase III of the program which involved AOSTRA and ten industry companies. By 1985, three promising pump designs from Phases I and II were modified for testing. As a result of Phase IIIA testing, negotiations were implemented for the manufacture of a tubing pump.

In Phase IIIB, two new styles of hydraulically driven downhole pumps were designed. However, results of field testing the pumps were disappointing due to mechanical problems with the pumps. The testing resulted in a new pump design, the components of which were patented. The project was completed in 1985.

To address another problem, Pengalta Research and Development was contracted by a consortium of six industry companies and AOSTRA to conduct a detailed review of

emulsion treating primarily from an equipment point of view. The study was completed in 1984 and will serve as the basis for additional developments. AOSTRA has supported and participated in a number of similar studies where an industry need for further research has been identified. These cooperative multi-client studies are an example of the efficient and effective way in which research monies can be spent with maximum input from interested clients. Industry-driven research has been an effective way of conducting "results-oriented" research which can be quickly applied in the field.

AOSTRA has taken an active role with a number of industry participants in the development of heavy oil production technology. While early attempts at applying combustion methods were not too successful, subsequent and continuing efforts to utilize combustion have been much more effective. As a result of astute observations of surrounding well performance, the important AWACT technology was developed. Such cooperative efforts between AOSTRA and industry have led to many improvements in heavy oil production procedures.



ALBERTA'S CONVENTIONAL OIL RESERVES ARE THE FOUNDATION UPON WHICH THE ALBERTA OIL INDUSTRY WAS ESTABLISHED. THE FLEDGLING INDUSTRY WAS BOOSTED INTO PROMINENCE WITH THE LEDUC OIL DISCOVERY IN 1947. THIS LED TO AN UNPRECEDENTED BOOM IN THE DEVELOPMENT OF CONVENTIONAL OIL RESERVES OVER THE LAST 40 YEARS.



- 1 HUSKY
- 2 ULSTER
- 3 AMOCO
- 4 BUMPER
- 5 GULF
- 6 VIKOR
- 7 CANADIAN HUNTER

Many new pools were subsequently discovered and quickly developed throughout the province. After a short period of primary production, most major pools were subjected to waterflooding to maintain oil productivity and increase oil recovery. Waterflooding continues to be the main enhanced recovery mechanism for Alberta oil pools. However, in recent years, hydrocarbon miscible flooding, or solvent flooding, has been introduced in a number of pools to further increase production.

By the end of 1988, a total of 6.9 billion m³ (43.2 billion barrels) of conventional oil (light and medium density) had been discovered in Alberta. The average recovery factor for pools producing by primary depletion is 23 percent. For pools producing under waterflood, the average recovery factor rises to 31 percent. Solvent flooded pools, by contrast, have an average recovery factor of 59 percent. For gas flooded pools, of which there is a limited number in the Province, the factor is 41

percent. The average oil recovery amounts to 30 percent for all pools based upon present recovery methods now being used within the pools.

With a 30 percent recovery factor, Alberta's initial total established reserves of light and medium density conventional oil are 2.1 billion m³ (13.1 billion barrels). However, cumulative conventional oil production to date has been 1.5 billion m³ leaving 0.5 billion m³ as remaining established reserves. At the current rate of production (1988) of 49 million m³ per year, Alberta's conventional oil life index is about eleven years. Recent forecasts indicate continued decline in production from conventional oil pools within Alberta.

Obviously, the 70 percent or 4.8 billion m³ (30 billion barrels) of presently unrecoverable conventional oil presents an attractive target for further recovery enhancement. In 1980 an enhanced oil recovery program was initiated by the Alberta government for the purpose of encouraging experimental enhanced recovery field projects in conventional oil reservoirs. AOSTRA administers the funding of the enhanced oil recovery program (EOR) which was added to its previously established research mandate involving the recovery of heavy oils and bitumens.

NOTE: ALL GEOLOGICAL SECTIONS ON THE PRECEDING PAGES ARE DIAGRAMATIC AND NOT TO SCALE.

ADVANCES IN RECOVERY TECHNOLOGY

AOSTRA has participated in a number of enhanced recovery projects since its mandate was expanded in 1980 to include experimental EOR projects in conventional oil. Initial response to a call for proposals in 1980 was limited.

In June 1981, AOSTRA acquired the result of a tracer test program that was conducted on two wells in the Cessford Basal Quartz "A" pool by Hudson's Bay Oil & Gas Company (now Amoco Canada). The tests were conducted to evaluate the pool as a candidate for caustic waterflooding. The Cessford pool is located in south central Alberta in a sandstone reservoir in the Lower Cretaceous formation at a depth of 930 m. The oil gravity is 26°API. Waterflood operations had been initiated in 1981 after the pool had produced for 23 years. The tracer tests concluded that the technique was effective for determining residual oil saturations before and after a caustic flood.

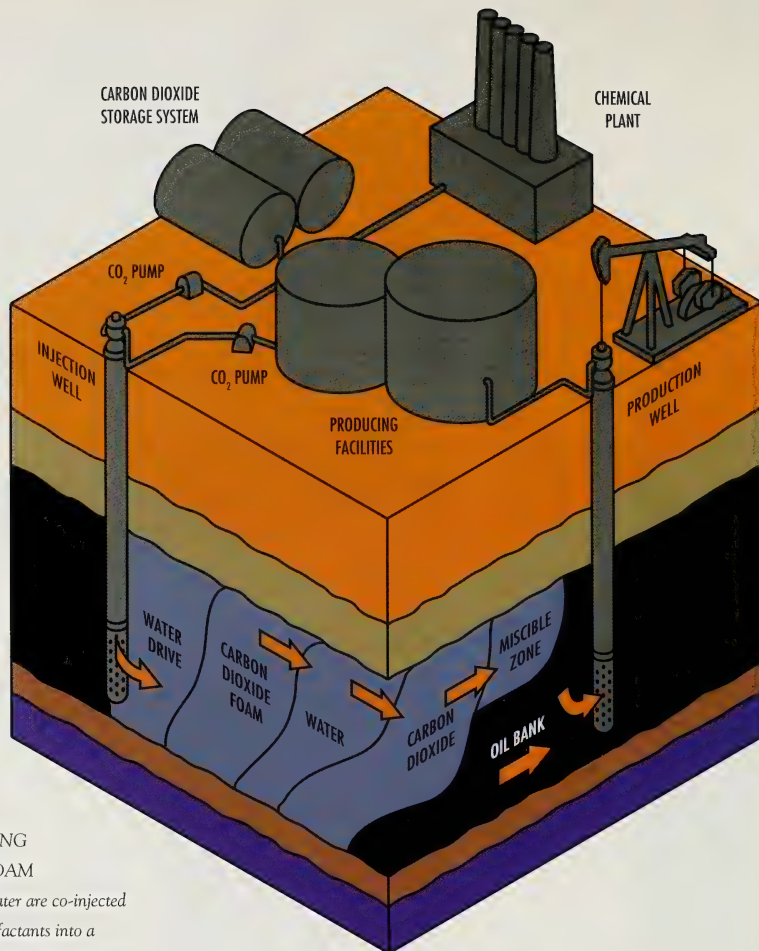
In July 1984, caustic waterflooding commenced in selected areas in the pool. Additional laboratory tests indicated that additional recovery could be achieved by the addition of polymer to the caustic flood. Injection of polymer was initiated in January 1985. The injection of caustic polymer chemical slugs has

MISCIBLE FLOODING WITH CO₂ AND FOAM

Carbon dioxide and water are co-injected with foam-forming surfactants into a previously waterflooded pool. The viscous foam selectively diverts the flow of injected CO₂ through oil-bearing parts of the formation, improving sweep efficiency and oil recovery.

continued until the present time. An agreement for AOSTRA participation in the pilot was completed in March 1986. Production response to the caustic polymer flood has been favourable in some parts of the pilot project.

In 1982, AOSTRA participated in a joint project with Husky Oil Operations Ltd. involving a series of CO₂ stimulation tests on wells in the Kitscoty area. The tests were designed to evaluate the production performance of wells following stimulation with large, immiscible slugs of CO₂. The tests were conducted in the Lloydminster (Kitscoty)

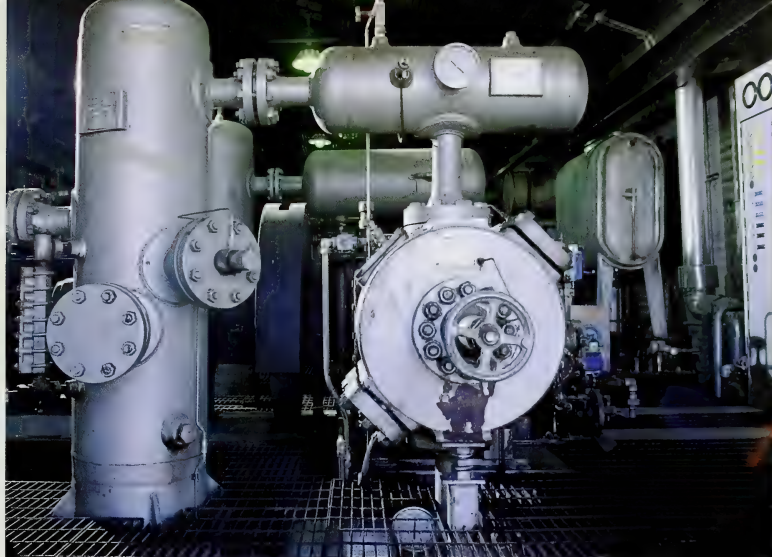


Sparky G pool located in east central Alberta in a Lower Cretaceous sandstone reservoir at a depth of 600 m. The oil gravity was 16°API. The results of the tests were not sufficiently encouraging to warrant further field work.

In 1983, Vikor Resources Limited, on behalf of AOSTRA and a number of industry participants, initiated a CO₂-miscible flood in the previously waterflooded and abandoned Joffre Viking pool in central Alberta about 20 km east of Red Deer. The reservoir is located in a Lower Cretaceous (Viking) sandstone reservoir. The pilot project was designed to test the ability of a CO₂-miscible flood to recover tertiary oil from a 3 m thick, light

gravity (40°API) oil reservoir which previously had been waterflooded. The initial pilot consisted of two 160-acre five-spot patterns. CO₂ was injected into one of the patterns commencing in January 1984. Water injection was alternated with CO₂ injection (WAG process) for injected fluid mobility control. CO₂ injection commenced in the second pattern in July 1984. Three slugs of CO₂, totalling 25% of the reservoir volume of the injected pattern, were injected over a period of three years in each injection well.

Production response to CO₂ injection was evident in 1984. This was the first miscible CO₂ project to be conducted in Canada.



Carbon dioxide compression facility at the Vikor miscible CO₂ Flood Project.

An expansion consisting of eight wells in an area offsetting the pilot was completed in 1985. A second expansion consisting of six more wells was completed in 1987 in an area near the original pilot. In addition, a mobility control test using a foam surfactant was started in 1988 in the original pilot area to determine if additional incremental oil could be produced.

The CO₂-flood pilot project operated by Vikor Resources is considered to be highly successful. Waste CO₂ gas is conveniently obtained from the nearby Alberta Gas Ethylene plant for injection into the Vikor project. Two expansions for the project are an unequivocal indication of its success.

In 1986, AOSTRA entered into an agreement with Canadian Westgrowth Limited (now Ulster Petroleum Ltd.) to acquire the operating data on the Retlaw Upper Mannville "B" Unit immiscible CO₂ project which is located northeast of Lethbridge. The objective of this project is to evaluate the performance of a CO₂-immiscible flood in a medium gravity reservoir. The injection of CO₂ commenced in October 1983. CO₂ was supplied to the project from the nearby Turin gas plant and was supplemented by trucked-in liquid CO₂ from nearby fertilizer plants. This is the first immiscible CO₂ flood

to be carried out in Canada. The project is still in operation and produced CO₂ is being recycled back into the reservoir.

AOSTRA has participated in the drilling of two horizontal wells in conventional oil reservoirs. AOSTRA, Bumper Development Corporation Ltd., and Enron Oil Canada Ltd. participated in the drilling of a short-radius horizontal drain hole in the Pekiska Rundle A formation of the Twining field. The project was located about 90 km northeast of Calgary. Bumper was the operator of the project which consisted of re-completing an existing well in the Twining Pool by drilling a single, short-radius drainhole from the cased well. Mechanical difficulties were encountered which precluded the comparison of productivity of a vertical well with a horizontal well in the Pekiska formation.

The second horizontal well was drilled by Canadian Hunter Exploration Ltd., with AOSTRA as a partner, in the Ethel Lake BHL pool in 1988. The purpose of the test was to assess the commercial feasibility of penetrating low permea-

bility oil-bearing carbonate reef reservoirs with a long-radius horizontal well where vertical wells had been proven to be uneconomical. The well was successfully completed mechanically and the potential of the well is currently being assessed.

An interesting and novel project in which AOSTRA is participating with Gulf Canada Resources Canada Ltd. is a nitrogen injection project in the Fenn-Big Valley "D-3B" pool located approximately 80 km east of Red Deer. The project started in 1987 with Gulf as the operator. Nitrogen was injected into a small Devonian reef reservoir to determine if the recovery of oil, natural gas liquids, and gas could be improved by the maintenance of reservoir pressure and the stabilization of fluid interfaces. The project was extended in 1989 to test the effectiveness of nitrogen foam to further enhance recovery.

In addition to the field pilot projects shown above, AOSTRA has shared in a number of laboratory and engineering studies listed here:

1. A laboratory program with Husky Oil Operations Ltd. to investigate the precipitation of asphaltene in light oils.
2. A multi-client laboratory study conducted by D.B. Robinson & Associates on the use of slim tubes to evaluate miscibility.
3. An anti-coning investigation on the use of special additives and bacteria for preventing water-coning.
4. A multi-client study by Hycal Energy Laboratories Limited to investigate the effect of CO₂ in displacing heavy oil and bitumen.
5. An engineering study by the Petroleum Recovery Institute to screen all Alberta oil reservoirs to identify prime candidates for possible pilot activity for each of eleven enhanced oil recovery processes.

In summary, AOSTRA has been involved in a number of important and novel enhanced oil recovery projects. The Vikor Joffre CO₂-flood currently shows the greatest promise of commercialization. Other projects are in too early a stage of development to evaluate their potential success.

THE ALBERTA OIL SANDS TECHNOLOGY AND RESEARCH AUTHORITY (AOSTRA), A PROVINCIAL CROWN CORPORATION ESTABLISHED IN 1974, HAS HELPED TO MAKE ALBERTA A WORLD LEADER IN OIL RECOVERY TECHNOLOGIES.

AOSTRA participates directly with members of the oil industry in a variety of experimental pilot projects, and operates the multi-user Underground Test Facility (UTF). AOSTRA also sponsors and acts as a catalyst for research by universities and other research institutions.

As a result of the investment by AOSTRA and its industry partners in the research and development of Alberta's hydrocarbon resources, a \$1-billion pool of technology is available for license from AOSTRA. AOSTRA has signed technology transfer agreements with government organizations in many nations plus numerous technology licensing agreements with industry.

RESOURCES WITH A FUTURE

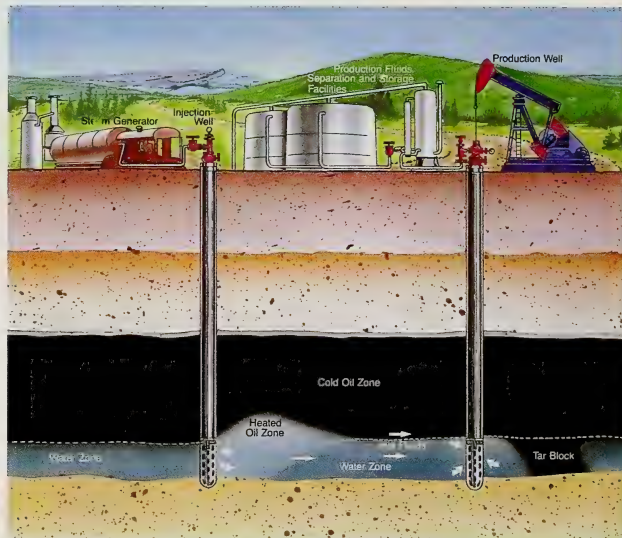
There are about 1.7 trillion barrels of bitumen in the oil sands and carbonate formations of Alberta plus about 8 billion barrels of heavy oil. Alberta has more than 40 percent of the bitumen in the world. Although supplies of low-cost light oil appear to be abundant

and currently satisfy more than 90 percent of the world demand for petroleum, they account for less than 25 percent of the remaining world petroleum reserves. As reserves of light oil are depleted and oil prices rise, the production of oils from the oil sands and heavy oil, and through enhanced oil recovery (EOR) from conventional sources, will assume increasing importance.

TECHNOLOGY BENEFITS

AOSTRA's billion-dollar pool of technology in the Alberta oil sands, heavy oil, and conventional oil resources means outstanding benefits for Alberta:

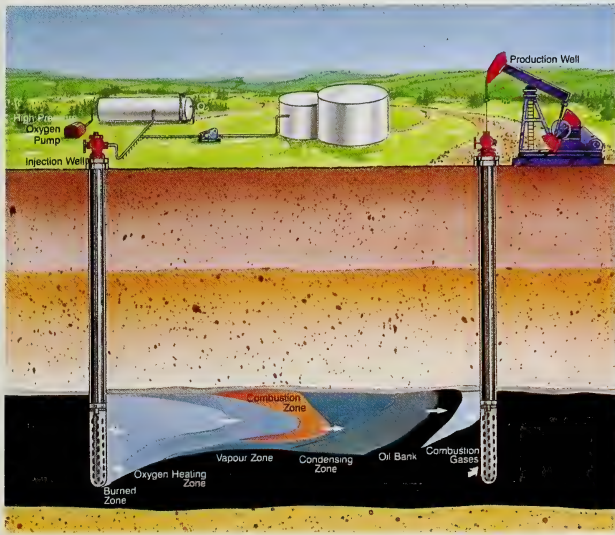
- innovative oil recovery technology;
- research, development, and commercialization of in situ processes, heavy oil upgrading, and bitumen extraction;
- assured hydrocarbon supply for Canada's domestic market and export requirements;
- environmentally sound technology.



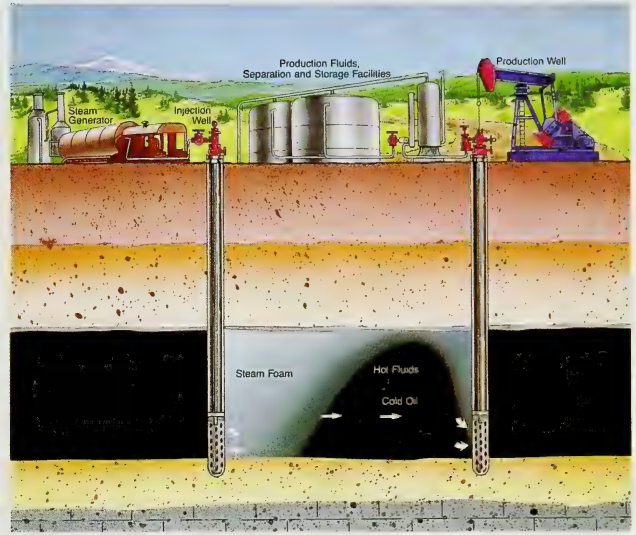
PRESSURE CYCLE STEAM DRIVE - A steam drive process with pressure cycles. Steam is injected into the reservoir without fracturing via underlying water sand which is permeable to the steam. This results in a radial heated zone at the base of the reservoir and mobilizes the overlying bitumen.



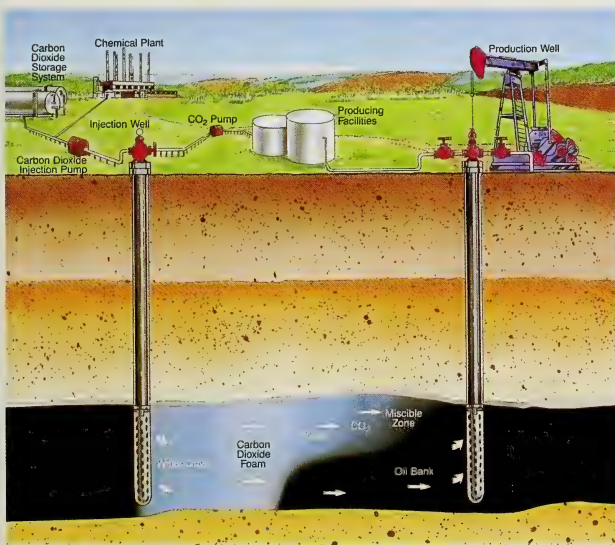
ANTI-WATER-CONING PROCESS - Water-coning into production wells is suppressed by periodic stimulation with injections of a non-condensable gas plus a chemical agent, introduced directly or via a central injector. The technique increases oil recovery and reduces the proportion of water produced.



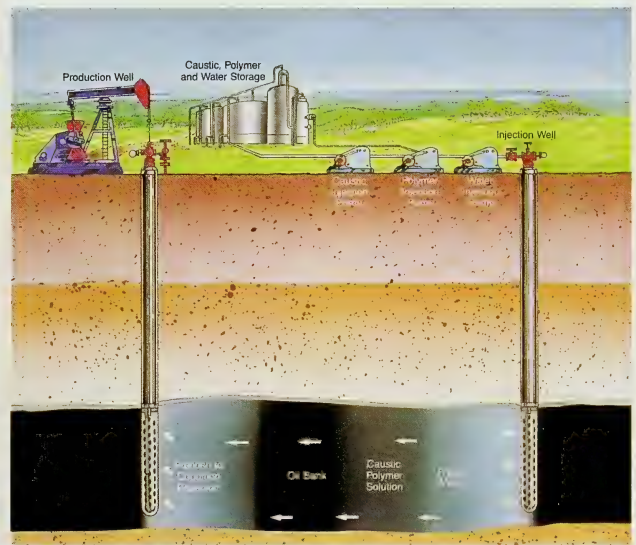
PRESSURE CYCLE OXYGEN FIRE FLOODING - This pressure-up/blow-down oxygen process is a follow-up to cyclic steam stimulation. During the pressure-up phase, oxygen and water are injected into the reservoir where combustion heats previously unrecovered areas. Oxygen injection is then terminated and mobilized bitumen is produced in the blow-down phase. This sequence is repeated a number of times.



STEAM FLOOD WITH FOAM - Foam-forming surfactant is co-injected with steam. The viscous foam blocks highly transmissible channels in the reservoir, increasing the pressure differential between injector and producer wells and improving sweep efficiency of the steam flood. The steam-foam injection program must be tailored to the recovery process and reservoir geology.



MISCIBLE FLOODING WITH CO₂ AND FOAM - Carbon dioxide and water are co-injected with foam-forming surfactants into a previously waterflooded pool. The viscous foam selectively diverts the flow of injected CO₂ through oil-bearing parts of the formation, improving sweep efficiency and oil recovery.



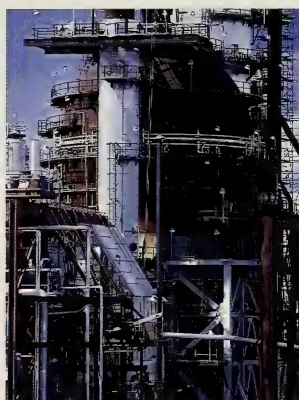
CAUSTIC POLYMER FLOODING - A reservoir salt water preflush to condition the formation is followed by the injection of a caustic polymer solution. This high pH viscous solution reduces interfacial forces between the oil and water and minimizes channeling, thus enhancing mobility control. Water is then injected to force the caustic polymer solution and the mobilized oil to production wells.



PETROLEUM PROCESSING



THE BITUMEN AND HEAVY OIL OBTAINED FROM ALBERTA'S OIL SANDS AND HEAVY OIL DEPOSITS RESEMBLE THE BLACK TAR OR ASPHALT USED TO PAVE ROADS. THESE SUBSTANCES ARE FAR TOO VISCOUS TO BE PUMPED THROUGH A PIPELINE TO A REFINERY IN EDMONTON, MONTREAL, TORONTO, OR VANCOUVER. MOREOVER, THE REFINERIES IN THESE CITIES ARE, IN GENERAL, NOT ADEQUATELY EQUIPPED TO REFINER THESE TARRY MATERIALS.

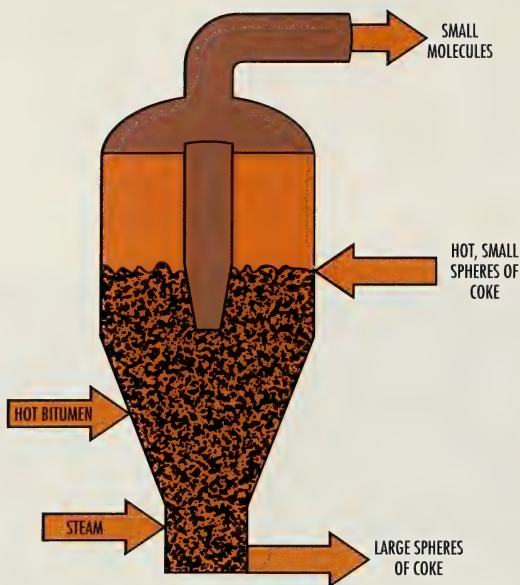


Our bitumens and heavy oils must therefore be refined here. Actually, they are only partly refined or "upgraded" to produce a light oil that we call synthetic crude or "syncrude." In the following pages the two upgrading processes that are currently being used commercially in Alberta are described, together with some of the new, more efficient processes which AOSTRA is examining.

Fluid cokers are used at Syncrude Canada Ltd. to upgrade bitumen to synthetic crude oil. Upgrading involves the complex processing of hydrocarbon fluids in refineries, such as the one at Suncor Inc., pictured at right.







COKING

The major reason why bitumen is so very viscous is that it contains mostly very large molecules. Upgrading processes simply break or "crack" these molecules into smaller ones. The least expensive way to induce molecular cracking is to heat the bitumen or heavy oil.

In practice, the bitumen is raised to a temperature of about 465° Celsius and then placed in a covered pot. The large molecules do not boil, rather they slowly crack into smaller ones. The smaller or lighter molecules boil off and are condensed elsewhere on cold surfaces. After a delay of several hours at this temperature, the cracking is complete. The material remaining in the pot is char or "coke." This process is called "delayed coking." It is the process used for many years by Suncor Inc. at their oil sands plant near Fort McMurray.

The amount of coke produced by the delayed coking process is about 23% of the weight of bitumen initially put into the pot. Commercially, the objective is to produce as much distillable liquid as possible. The coke has little commercial value, and can be an environmentally undesirable product.

Slightly less coke and slightly more distillable liquid is obtained if the bitumen is heated to a temperature higher than that used in Suncor's delayed coker. To do this, Syncrude Canada Ltd. uses a more complicated process than that of Suncor's. This process, called "fluid coking," heats the bitumen to about 530° Celsius.

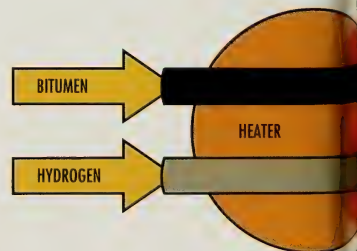
In the fluid coking process, hot steam is blown upwards rapidly through a large vessel partly filled with small spheres of hot coke. The velocity of the steam is so high that the small spheres of coke are suspended and move about freely much as if they were a liquid. Into this "fluid" is sprayed the hot bitumen.

The bitumen cracks. The small molecules boil off and before they can recombine to form heavier molecules, are carried away quickly by the steam to be condensed elsewhere. The remaining coke accumulates on the small spheres; consequently these spheres grow, settle, and are removed from the bottom of the vessel. New small hot spheres of coke are added at the top of the vessel. This process is a continuous one and is shown in the illustration.

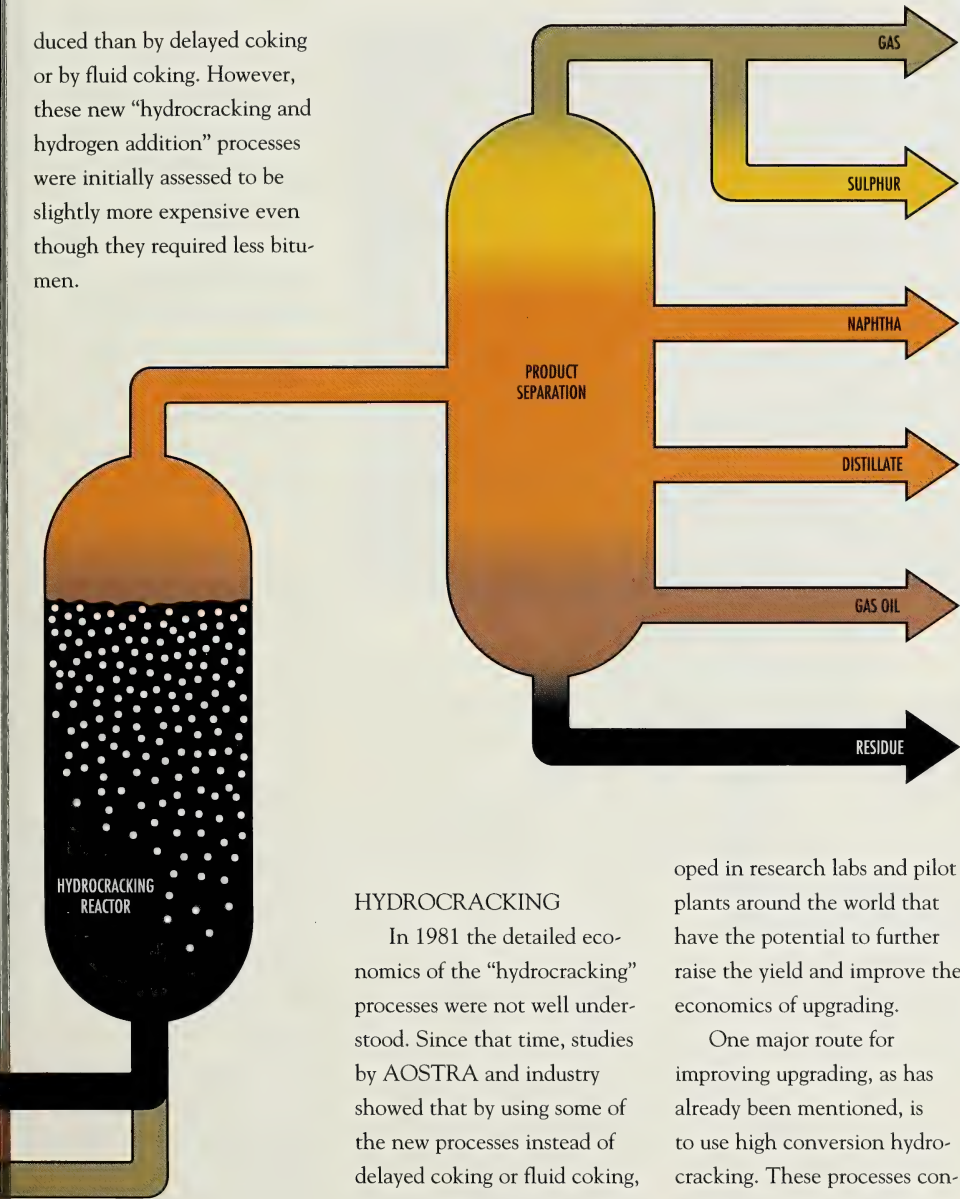
There is a risk in being the first to apply new technology on a commercial scale. Syncrude Canada Ltd. and Great Canadian Oil Sands Ltd. (now Suncor Inc.) were the first to develop commercially viable oil sands plants. With so much money and so many careers at stake, the sensible low risk approach was to use well established conventional technology. Delayed coking and fluid coking fall into this category. And even in the sixties these processes were well understood.

In commercial operations, today, the cost of producing 100 barrels of bitumen is approximately the same as the cost of upgrading it. However, the upgrading yields only 86 barrels of synthetic crude.

Given these realities and the desire to make the best use of Alberta's oil sands, there is an enormous incentive to develop and try out new, more efficient processes. Those tested by AOSTRA, and described below, can provide about 104 barrels of synthetic crude from 100 barrels of bitumen. These marked increases in percentage yield involve treatment with hydrogen gas. First the bitumen is heated from about 430° to 470° Celsius and mixed with hydrogen in a high pressure vessel, at about 12 to 24 megapascals (120 to 240 atmospheres). Under these conditions, hydrogen reacts with the bitumen and with the cracked molecules. More small molecules and less coke are pro-



duced than by delayed coking or by fluid coking. However, these new "hydrocracking and hydrogen addition" processes were initially assessed to be slightly more expensive even though they required less bitumen.



In hydrocracking processes, the combination of cracking and hydrogen addition results in a high yield of liquid products.

HYDROCRACKING

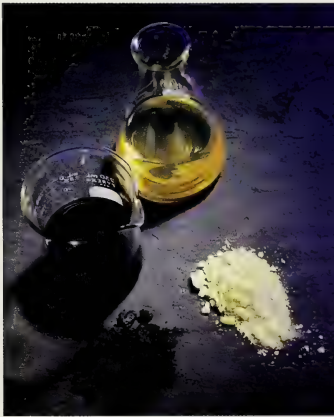
In 1981 the detailed economics of the "hydrocracking" processes were not well understood. Since that time, studies by AOSTRA and industry showed that by using some of the new processes instead of delayed coking or fluid coking, commercial producers could save as much as \$4 per barrel of synthetic crude! The commercial incentive to test such new processes was therefore very strong.

Studies on the technology and economics of upgrading by AOSTRA and industry have indicated other options devel-

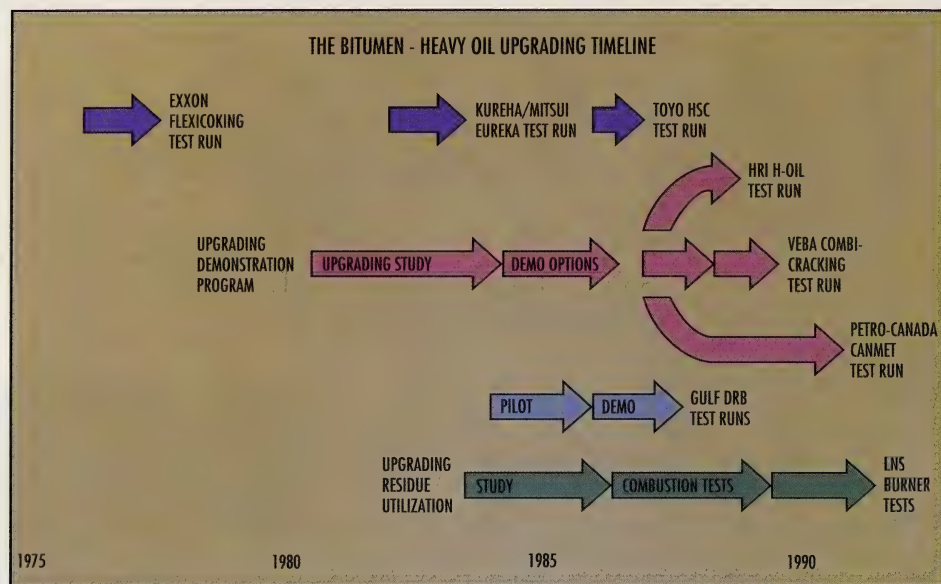
oped in research labs and pilot plants around the world that have the potential to further raise the yield and improve the economics of upgrading.

One major route for improving upgrading, as has already been mentioned, is to use high conversion hydrocracking. These processes convert over 90% of the normally undistillable material, commonly known as the vacuum bottoms or residues, to lighter products. Liquid yields of synthetic crude are over 100 vol% of the bitumen used. Petro-Canada, VEBA Oel, Hydrocarbon Research Inc. (HRI), and others have developed processes involving this type of

Heavy, black bitumen is converted to an equal volume of high quality synthetic crude oil and a small quantity of upgrading residue. Sulphur, an impurity in the bitumen, is recovered as a valuable by-product.



high conversion hydrocracking. The basic problem with these new processes is that while they indicate high yields and improved economics, they had not been proven commercially and as a result would not be chosen for commercial ventures. Because they had not been chosen for commercial-scale operations, they could not be considered as commercially proven. This circular argument could go on forever unless someone is willing to break the circle. Some group has to demonstrate that the process works on commercial-size equipment before it can be licensed for commercial use.



THE NEED FOR COMMERCIAL SCALE PROCESS DEMONSTRATION TESTS HAS BEEN LONG RECOGNIZED BY AOSTRA. IN FACT, ONE OF AOSTRA'S FIRST PROJECTS IN 1976 WAS A TEST RUN TO DEMONSTRATE THE PERFORMANCE OF EXXON'S FLEXICOKING PROCESS ON ATHABASCA BITUMEN. AOSTRA PROVIDED 2400 M³ (15,000 BARRELS) OF BITUMEN AND ARRANGED FOR ITS PROCESSING AT THE FLEXICOKING COMMERCIAL DEMONSTRATION UNIT IN BAYTOWN, TEXAS.

In 1982, AOSTRA supported a test program using the Eureka Process developed in Japan by Kureha. This test program showed clearly that the Eureka Process worked well on Alberta bitumen feedstocks. A similar test program was successfully completed in 1986 for the Toyo "HSC" process.

In 1986, AOSTRA and Gulf Canada undertook a process demonstration test of the Gulf Donor Refined Bitumen (DRB) Process. This process, which utilizes thermal cracking of bitumen and liquid phase hydrogenation using a process-derived hydrogen-donor solvent, was developed by Gulf's research team at Sheridan Park, Ontario, with AOSTRA support, from 1983 to 1988. A small (one barrel per day) pilot plant was initially used to show

that the process worked and a positive hydrogen-donor balance could be achieved. To demonstrate the DRB process, on semi-commercial scale equipment, the test project was undertaken in France on an experimental heavy oil mini-refinery – the ASVAHL platform. The test at ASVAHL proved out the DRB process chemistry, but further design, development, and demonstration were required on the reactor itself.

THE UPGRADING DEMONSTRATION PROGRAM

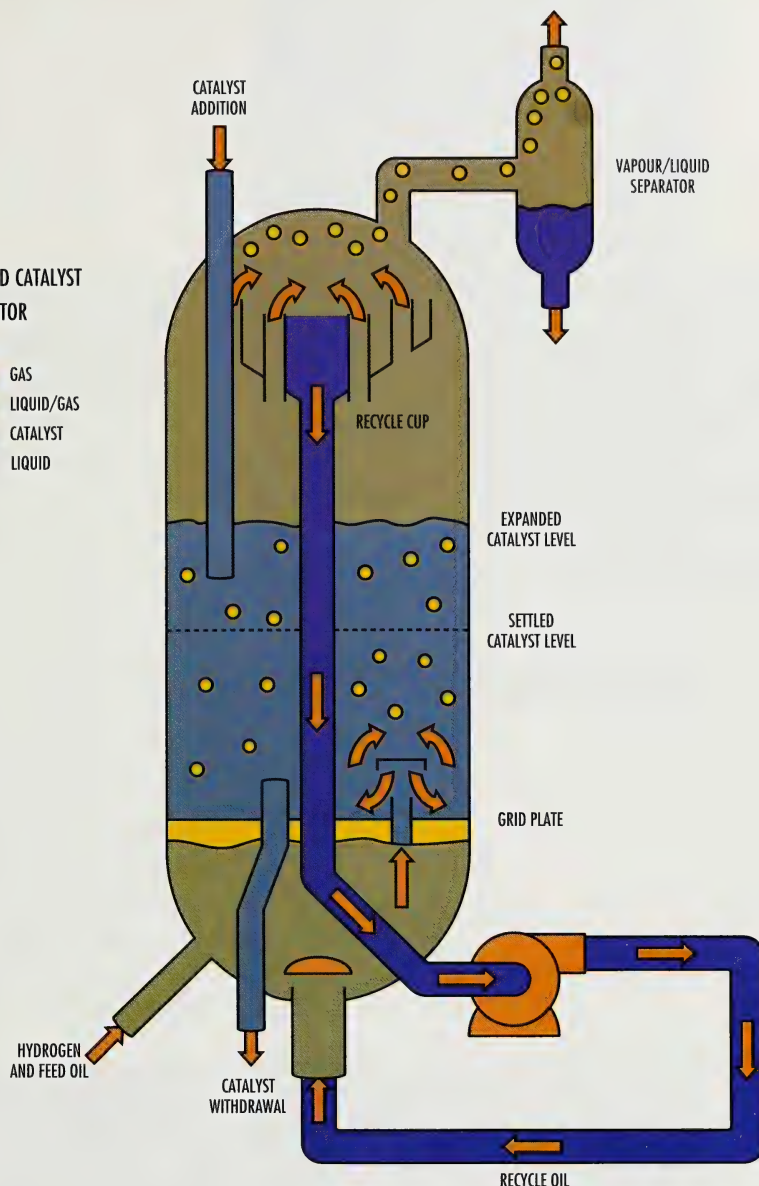
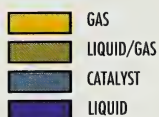
In 1985, AOSTRA formed a consortium with 12 oil industry partners to define upgrading demonstration projects based on the best of the emerging upgrading technologies, to see how their development could be accelerated and commercial viability achieved. In this program three processes were finally selected and demonstration projects were planned in detail for High Conversion H-Oil, VEBA Combi-Cracking, and CANMET Hydrocracking. AOSTRA has moved ahead with bilateral agreements for demonstration tests with the process developers and licensors based on the interest, direction, and moral support from the oil industry.

The H-Oil® High Conversion Demonstration Program:

The first test in the Upgrading Demonstration Program involved the H-Oil® High Conversion Demonstration system. The H-Oil® process is one of a group of well known, ebullated-bed, hydrocracking processes which have been commercially applied for many years around the world. Some local examples would be the choice of H-Oil®, followed by coking, for Husky's BiProvincial Upgrader Project and Syncrude's capacity addition program, which involves the installation upstream of the fluid cokers of a similar process – LC Fining®, licensed by Lummus-Crest.

Although both licensors have confidence that their process can be applied at conversion levels over 85%, this had not yet been commercially demonstrated. The H-Oil® process installed by Texaco at Convent, Louisiana, has the provisions built in for high conversion operation but it has not yet operated in that mode. AMOCO has operated the L-C Finers at their Texas City refinery at over 80% for short periods. There remained a conservative skepticism in the industry about the sustained high conversion operation of these processes.

EBULLATED CATALYST BED REACTOR



To demonstrate that high conversion operation is indeed feasible with Alberta feedstocks, AOSTRA agreed to sponsor a test with HRI. The six-week test on Cold Lake bitumen was carried out through December 1986 and January 1987 on the 30 barrel per day process development unit in Lawrenceville, New Jersey. This unit permitted daily catalyst addition and withdrawal so

it could simulate satisfactorily the commercial mode of operation with process-seasoned, or equilibrated catalyst.

The objectives of the test program were to confirm the commercial viability of the high conversion H-Oil® process on Cold Lake vacuum residue and to provide a database to design and guarantee commercial facilities utilizing the process. These objectives were achieved.

Following some minor start-up problems due to power dips, the test ran for the planned 41 days in a smooth continuous operation. Residue conversion levels averaging 85 and 92 vol% were achieved. Successful operation for 21 days at 92% conversion, using an equilibrated catalyst, demonstrated that the H-Oil® process can operate at high conversion on Alberta feedstocks.



Over 1600 m³ of diluted bitumen was shipped to Europe for the VEBA Combi-Cracking Test Program. Some of the high pressure vessels of the VEBA Pilot Plant are pictured below.

The Veba Combi-Cracking Test Program:

Two VEBA Combi-Cracking (VCC) feed tests have been completed in Germany. The first was a test on Cold Lake bitumen which was approved by AOSTRA in September 1986 and is funded 80% by AOSTRA and 20% by VEBA. Based on the success of

the first test, and the availability in Europe of Athabasca bitumen residue, a second test was undertaken early in 1988 on the Athabasca feedstock. AOSTRA provided 60% of the funding for this test.

The VEBA technology is a high conversion hydrocracking process which integrates the primary hydrocracking in a liquid phase reactor with the secondary hydrotreating in a gas phase reactor, hence the name VEBA Combi-Cracking (VCC). The process is an outgrowth of the Berguis-Pier coal liquefaction technology developed in the thirties in Germany and was used to convert conventional crude oil residues in the fifties. With the

increase in heavy oils in the world oil market VEBA has revived and adapted the technology for upgrading heavy crude oils and tar sands bitumens. Pilot plant tests have shown the process can operate at over 90 wt% conversion and produce synthetic crude yields of about 105 vol%. Process equipment had been proven on a commercial scale through the recent operation of a 200 tonne/day coal liquefaction plant at Bottrop, West Germany. There was a need to demonstrate, through large scale pilot plant tests on Alberta feedstocks, that the process is ready for commercial application in the upgrading of bitumen.



The initial VCC test program involved the procurement and shipment of over 1600 m³ of diluted Cold Lake bitumen to Europe. This was then distilled at a refinery near Antwerp. The straight run distillates and vacuum residue were shipped to Gelsenkirchen, West Germany, for the demonstration test in May 1987.

The objectives of this initial test were to operate the 30 tonne-per-day VCC pilot plant unit in Gelsenkirchen, West Germany, on Cold Lake bitumen. A 21 day steady-state period with a target of 94 wt% conversion was defined. This would demonstrate the capability of the process, provide a data base for process design and guarantee, as well as generate sufficient residue for tests in other AOSTRA-sponsored programs.

The test started May 3, 1987, with the introduction of Cold Lake bitumen feed and ran continuously until June 1. The integrated VCC Process was tested with vacuum residue feed to the liquid phase reactor (LPH) and three distillate streams to the gas phase reactor (GPH): consisting of straight runs, hot separator overheads and vacuum tower distillates.

The test was very successful. Smooth continuous operation was demonstrated throughout the test period of

almost 700 hours. The steady-state period with all systems operating on specification was over 17 days and included four balance periods.

Based on the success of the initial test and a growing interest in upgrading Athabasca bitumen using VCC technology, VEBA and AOSTRA agreed to a second test. The objectives and test program were much the same as the initial test. The feedstock was different – in this case Athabasca bitumen residue which had already been shipped to Europe but had not been used in the Gulf DRB test program. A 17 day test on the Athabasca feedstock was successfully completed on the VEBA pilot plant in January 1988.

Steady high conversion operation (94%+) was maintained for the planned duration of 15 days.

The series of successful tests just described provides an excellent design data base and confidence that the VCC Process is ready for commercial application for bitumen upgrading in Alberta.

The CANMET Hydrocracking Test Program:

The last segment in this upgrading demonstration series was a test run in early 1989 on the CANMET Hydrocracking Demonstration Unit in Montreal.



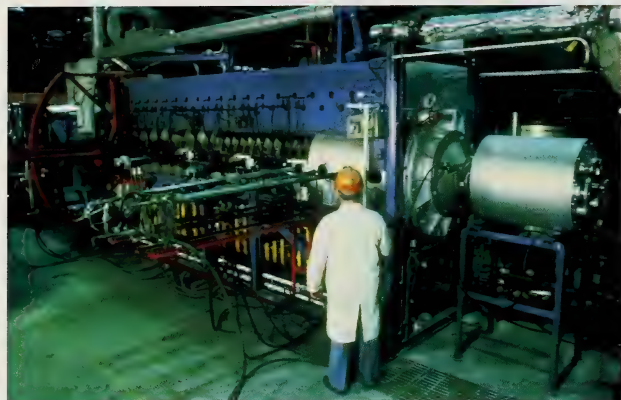
The CANMET Hydrocracking Demonstration Unit at the Petro-Canada refinery near Montreal.

CANMET Hydrocracking is a hydrogen addition upgrading process which was developed in the 1970's by the Federal Government at the Canadian Centre for Mineral and Energy Technology (CANMET). The process involves thermal cracking in the presence of hydrogen and an iron and/or coal-based additive. Using this process over 90% of residual oil or pitch can be converted in a single stage to higher value products such as naphtha, distillate, and gas oil.

Petro-Canada acquired rights to the CANMET technology in 1979 and in 1981 reached an agreement with Lavalin Inc. to jointly develop and commercialize the process. As part of this development program, the practicality of the technology has been proved on a commercial scale in an 800 tonnes per day Demonstration Plant at Petro-Canada's Montreal refinery.

Since its startup in 1985 Petro-Canada have used the demonstration plant for commercial operation as an integral part of the operating refinery and to further develop the process design. For example, the additive system in the demonstration plant has been revised and greatly simplified. Feedstock for the demonstration plant has generally been the refractory bottoms from the refinery's regular diet of light crudes. Pitch conversion on this feedstock has generally been in the 65 to 80% range.

In late 1987 high conversion operation was demonstrated when a special 250,000 barrel batch of Cold Lake blend was brought into the refinery. Pitch conversion levels of 86% were consistently maintained on the blend of Cold Lake and IPL bottoms during this operation.



WHEN BITUMEN IS UPGRADED TO SYNTHETIC CRUDE OIL, A RESIDUE BYPRODUCT IS GENERALLY PRODUCED. FOR SOME PROCESSES THIS RESIDUE IS A SOLID CARBONACEOUS MATERIAL, LOOSELY CALLED COKE. HYDROCRACKING PROCESSES ON THE OTHER HAND PRODUCE PITCH — A BLACK TAR WHICH IS A SOLID AT NORMAL TEMPERATURES.

ABOVE: The tunnel furnace at the CANMET Combustion Research Laboratory near Ottawa. This furnace was used to test the combustion characteristics of upgrading residues.

The energy value of the hydrocarbons in the residues make them valuable resources but the economic utilization of these materials by environmentally safe processes is difficult owing to the high level of contaminants, such as ash, sulphur, nitrogen compounds, and metals. Currently, commercial upgrading plants utilize some of the coke produced as energy within the total process but most of the coke is stockpiled. The coke, when burned, produces significant amounts of sulphur oxides and particulates.

To permit greater recovery of energy from our bitumen resources and to prevent environmental damage from emissions, AOSTRA and partners

from industry have sponsored, since 1983, a multiphase research and development project on upgrading residue utilization.

The first phase of the study defined the problem residues, and outlined potential utilization strategies, such as clean combustion techniques and gasification for fuel or hydrogen production.

The second phase, completed in late 1985, was a technical, environmental, and economic assessment on various utilization techniques.

The general conclusion of this engineering study was that upgrading residues had a negative economic value. The difficulties and expenses involved with clean combustion and gasification generally exceeded the fuel value of the residues when compared to other fuels in Alberta.

The first recommendation of the study program was therefore to minimize the production of residues and to choose upgrading processes which result in the maximum possible conversion of bitumen to liquid fuel products.

The most commercially promising uses for residues were clean combustion processes. These included combustion of liquid residues combined with scrubbers to absorb undesirable emissions, as well as fluidized bed combustion systems.

A third phase was initiated to demonstrate that these residues could in fact be successfully burned. Several programs were undertaken using test furnaces at the CANMET Combustion Research Laboratory (CCRL) near Ottawa and the Energy and Environmental Research Corporation in California.

These tests demonstrated that the pitch residues can be handled as high melting point, high viscosity liquids and be burned in conventional furnaces. Higher fuel temperatures and greater attention are required but the combustion characteristics, flame properties and heat transfer rates are similar to normal heavy fuel oils. Scrubbing would of course be required to meet environmental standards.

Research on the utilization of upgrading residues is continuing. AOSTRA and industry have recently initiated a test program with TransAlta Technologies on their Low NO_x SO_x (LNS) burner designed to minimize emissions of oxides of nitrogen (NO_x) and oxides of sulphur (SO_x). With the LNS burner, pollutants are reacted in the combustion process and removed with the slag.

The special slagging combustor was originally developed for coal but may be applicable for other problem fuels such as upgrading residues and heavy liquid fuels.

CONCLUSION

The complex series of commercial-scale demonstration test programs has significantly reduced the risks involved in the introduction of new upgrading technologies. The test procedures have provided an excellent data base for engineering design and process guarantee specifications. Significantly more and better choices for upgrading processes are now available for commercial projects. These high conversion processes from HRI, Petro-Canada, and VEBA offer higher yields of liquid products, improved product quality, lower environmental impact, and improved economics, when compared to existing commercial upgrading processes.

AOSTRA's work in this area is continuing. The upgrading residue utilization program described above focuses on improved energy resource utilization and reduced environmental problems. Test programs are also underway on more fundamental aspects of upgrading. Two examples of ongoing work are the Hydrocarbon Upgrading Program at the Alberta Research Council and the development of the High Conversion, LC-Fining Process with Lummus Crest Inc.



Bitumen upgraders at Syncrude Canada Ltd. near Fort McMurray.

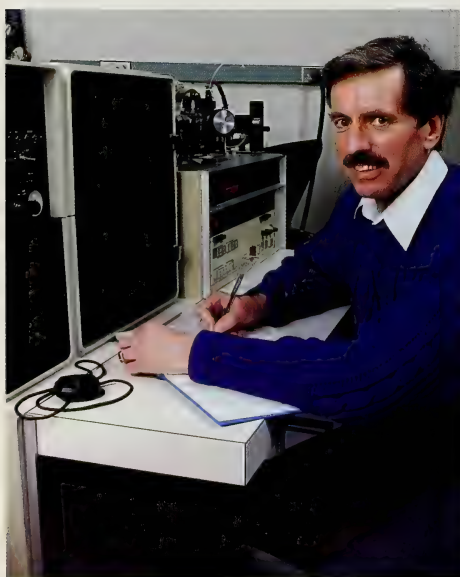


ENVIRONMENT



THE INCREASED ENVIRONMENTAL AWARENESS OF THE INDUSTRIALIZED WORLD HAS BROUGHT ABOUT A SIGNIFICANT CHANGE IN ATTITUDES TOWARD INDUSTRIAL DEVELOPMENT. TODAY, THE CHALLENGE FACING ALL INDUSTRY (INCLUDING THE HEAVY OIL AND OIL SANDS INDUSTRIES) IS TO SUSTAIN PRODUCTION, WHILE ENSURING A MINIMUM IMPACT ON THE SURROUNDING ENVIRONMENT.

The advancement of relevant environmental research, as well as the compilation, assessment, and dissemination of pertinent technical information, are part of the mandate of AOSTRA. This mandate is set out in the Alberta Oil Sands Technology and Research Authority Act.

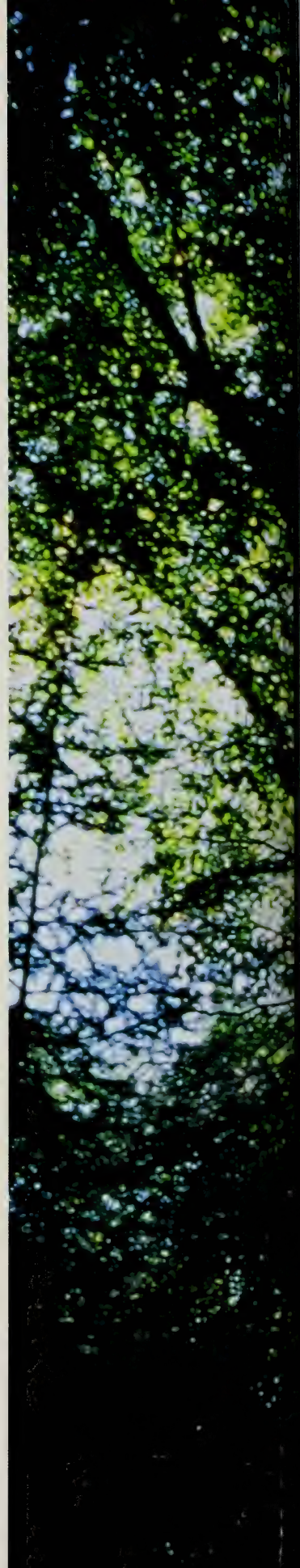


Eric Peake in front of a GC/MS (Gas Chromatograph/Mass Spectrometer). This instrument is useful in characterizing the organic components of different oil and produced water streams.

AOSTRA projects, while not customarily identified as being directed solely at environmental issues, frequently deal with the development of technologies which offer potential environmental benefits if successfully applied commercially. AOSTRA remains committed to development of environmentally acceptable technology and will continue to fund projects that will assist in the identification and mitigation of environmental hazards generated by the production and processing of oil sands bitumen and heavy oil.

This commitment is exemplified by AOSTRA's continuing involvement in research and development of technologies associated with:

- treatment and recycle of produced water; or,
- preservation of air quality;
- reducing the toxicity of oil sands products;
- treatment and clean-up of oily wastes; and
- methods to eliminate or reduce the size of tailings ponds.





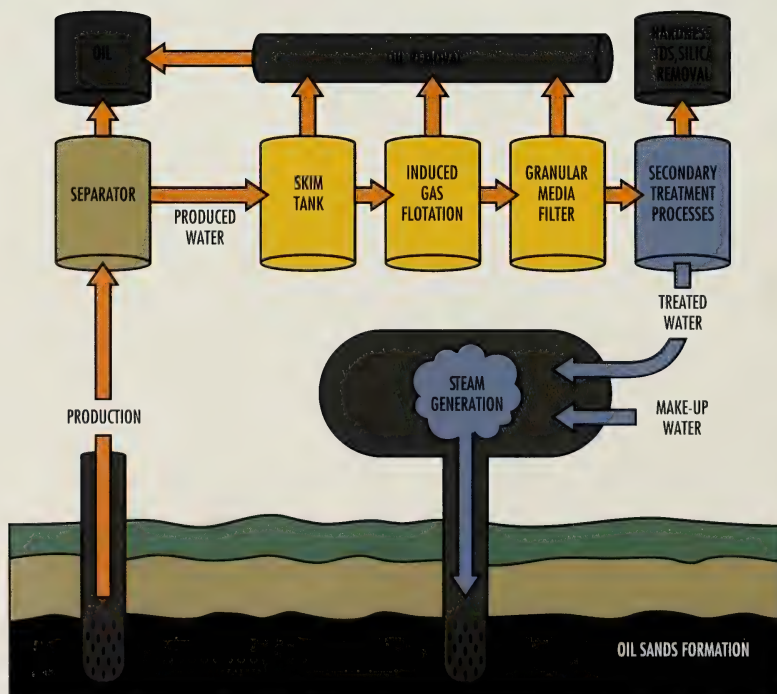
WATER CO-PRODUCED WITH BITUMEN AND HEAVY OIL, FROM IN SITU RECOVERY OPERATIONS, PRESENTS UNIQUE PROBLEMS FOR DISPOSAL AND FOR RE-USE. BECAUSE OF LIMITED SUPPLIES OF FRESH WATER, IT IS DESIRABLE AND SOMETIMES IMPERATIVE TO RECYCLE ANY WATER THAT MAY BE RECOVERED FROM IN SITU OPERATIONS, RATHER THAN DISPOSE OF IT COMPLETELY AS PRODUCTION WASTE.

The quantity of good quality water needed for steam-based in situ processes is five to seven times the volume of oil produced. Recycling of produced water to meet these steam generation requirements offers two significant environmental advantages; there is a lower consumption of fresh water resources, and the volume of waste water requiring deep-well disposal is also reduced.

Water produced during the in situ recovery process contains several impurities which must be removed if this water is to be used as feedwater for a steam generator. One of these categories of impurities is total dissolved solids (TDS) which includes principally the soluble salts of sodium, potassium, calcium, and magnesium. Other impurities typically present include oil and suspended solids, which are usually removed by gravity settling, induced gas flotation, and granular media filtration. Also, silica and hardness are eliminated by hot lime softening, with final polishing for hardness removal by ion exchange.

Produced waters in Alberta have been roughly classified according to total dissolved solids (TDS) levels. Waters produced from the Peace River deposit typically have low TDS (less than 8,000 mg/L) and do not require treatment for TDS reduction. Lindbergh area produced waters have very high TDS levels (17,000 mg/L and up). Therefore the water treatment scheme is focused on the reduction of TDS to a level acceptable for steam generation. A third type of water is that with a moderate level of TDS (8,000–17,000 mg/L) and a moderate level of silica. Cold Lake area produced water falls into this category.

A requirement for operators to maximize recycle of produced water is embodied in the Province's long term management plans for in situ oil sands facilities in Alberta. This is apparent from the recently released "Water Recycle Guidelines," issued by the Energy Resources Conservation Board and Alberta Environment. The treatment of produced water to create boiler-feed quality water has been an AOSTRA objective for many years. Several technologies have been tested or studied since 1980, with varying degrees of success, in a continuing effort to develop successful and economic solutions to this important environmental concern.



Schematic of a typical conventional produced water treatment facility, with recycle for steam generation.

In 1981, AOSTRA and a number of industry companies initiated the "AOSTRA/Industry Produced Water Treatment Study." The objectives of the study were to identify and evaluate existing and emerging technologies, together with processing systems applicable to the treatment of in situ produced water. In order to establish quantitatively the treatment requirements, produced waters from each of the major in situ production areas in Alberta were evaluated.

A variety of technologies and processes were identified and assessed in various configurations for free oil and grease removal, softening, silica removal, dissolved solids reduction, and the removal of dissolved organic material. The study progressed to the development of a preliminary design of facilities, and estimation of the costs for a field test program to further test and evaluate several process options. However, in 1985 the project was cancelled as a direct result of the economic downturn within the oil industry.

Even though the AOSTRA/Industry Produced Water Treatment Project did not lead directly to joint process demonstration projects with the in-



dustry participants, AOSTRA remained committed to the development and demonstration of effective water treatment processes. AOSTRA has since entered into a number of bilateral project agreements with both process developers and user companies to evaluate and test promising technologies for the treatment of produced waters.

AOSTRA and Walden Division of Abcor Inc. examined the use of ultrafiltration membranes, in combination with reverse osmosis, for removal of suspended solids and high molecular weight hydrocarbons. While the performance testing of these processes was judged to be moderately successful, it was clear that longer-term continu-

ous testing would be needed to properly evaluate these technologies. An independent comparative economic evaluation of the Walden membrane system relative to commercially available conventional water treatment processes indicated that, while the capital costs were comparable, the operating costs of water treatment systems employing the Walden technology could be 20-25% higher than conventional systems.

Oil emulsion mini plant; used in the study of produced water treatment.

Shell Canada and AO STRA commissioned a produced water treatment pilot plant at the Shell Peace River in situ project site to examine silica removal requirements.



In addition to the Reverse Osmosis work conducted by Walden Division, AO STRA funded an investigation by Dr. A.K. Mehrotra, at the University of Calgary, into the effectiveness of the reverse osmosis technique in the separation of dissolved constituents from waste water. It was found that the process provided 96 to 99% removal of total solids, while TDS was reduced to levels of 20–50 mg/L. However, two prefilters with 25-micron and 0.5-micron pores were needed to remove residual oil and other organic compounds in order to avoid clogging.

In 1980, AO STRA entered into an agreement with Geo-Chem Laboratories (Canada) Ltd. and later Gemini Biochemical Research Ltd., to conduct an initial investigation into microbial upgrading of produced water. It was found that almost all of the bitumen and suspended solids could be removed from the produced water by such treatment. Most of the tests were carried out at ambient temperature, although some acclimated bacterial cultures (capable of growth at 60°C) were found to give a similar degree of bitumen removal, but at the expense of a longer residence time. Further work on the project,

however, was not initiated, as the technical and commercial potential of the process did not appear to be economically viable at the time.

In 1983, a patented "Brackish Water Treatment System," consisting of electrodialysis, ozonation, and dissolved air flotation, was assessed by Hankin Environmental Systems Inc., through funding from AO STRA. The results of field trials at the AO STRA/Shell Peace River in situ pilot plant indicated that the Hankin system was capable of producing a high quality treated water, although there was evidence of membrane fouling. The economics of the system were shown to be comparable

to conventional systems, but only for large utility boiler installations. AO STRA chose not to pursue further development of this process.

In 1986, Shell Canada Ltd. and AO STRA commissioned CH₂M-Hill Engineering Ltd. to design and operate a pilot plant to investigate the feasibility of using high silica produced water as steam generator feedwater. The pilot incorporated treatment facilities for the removal of oil and hardness, but did not remove silica from the produced water. The key objective of the test program was to verify the treatment



Limited) to undertake a field test of processes for the treatment of produced water typical of the Lindbergh area of Alberta. A common problem for all companies using steam stimulation in the Lindbergh area is the extremely high level of total dissolved solids (TDS) found in the water co-produced with the bitumen.

Based on a review of the technologies, conducted by Environment Canada's Wastewater Technology Centre (WTC), vapor compression evaporation (VCE) was ranked as the most technically advanced process for the treatment of high TDS waters.

Results of pilot tests indicated that TDS removal by vapour compression evaporation is technically achievable. However, pretreatment of the feedwater going into the evaporator unit was necessary to stabilize the characteristics of the water. Consequently, the costs of the system made the process less economically attractive than first anticipated. An alternative to the evaporation process is electrodialysis. Accordingly, in 1988, a second phase of the project was initiated in order to test electrodialysis. Laboratory testing of ultrafiltration and microfiltration processes as a pretreatment to the electrodialysis

is currently being evaluated. Once a pretreatment is selected, the electrodialysis pilot plant will be designed, installed, and operated to assess its effectiveness.

In 1988, AOSTRA joined Monenco Consultants Limited, Energy Mines and Resources Canada (CANMET), and Supply and Services Canada to investigate the Thermal Lime Softening Process (TLS). This process, proposed by Monenco, incorporates the best features of the Hot Lime Softening and Thermal Softening processes to remove hardness and silica. Presently, the only commercially available technology to treat Cold Lake produced water for reduction of hardness

and silica is the Hot Lime Softening process. The disadvantages of Hot Lime Softening are its relatively high capital and operating costs and the production of a lime sludge, which requires disposal in an environmentally acceptable fashion.

Favourable results from the bench scale phase of the program have paved the way for construction and operation of a larger scale continuous flow pilot plant. If these pilot scale studies prove successful, the development of this technology will enter into a commercialization phase.

process and to determine if the steam generator could operate on 100 percent produced water having a high silica concentration without fouling the boiler tubes.

The project was considered successful and it will assist in setting new operating parameters for Shell's commercial water treatment and steam generation facilities at the Peace River complex.

In the fall of 1986, AOSTRA joined with Environment Canada and five oil industry companies (Amoco Canada Petroleum Company Ltd., Dome Petroleum Limited, Murphy Oil Company Ltd., PanCanadian Petroleum Limited and Westmin Resources



The Vapour Compression Evaporation unit used in phase I of the AOSTRA/Environment Canada/Industry-Lindbergh area produced water treatment study.

OVER THE LAST FEW YEARS AO STRA HAS BEEN INVOLVED IN THE DEVELOPMENT OF SEVERAL TECHNOLOGIES AIMED AT EITHER MINIMIZING WASTE GENERATION IN THE PRODUCTION AND PROCESSING OF OIL SANDS BITUMEN OR AT THE ACTUAL TREATMENT AND CLEAN-UP OF OILY WASTE PRODUCTS. AO STRA, TOGETHER WITH UMATAC INDUSTRIAL PROCESSES OF CALGARY, HAS DEVELOPED AN EXCITING NEW TECHNOLOGY KNOWN AS THE AO STRA TACIUK PROCESSOR (OR ATP).

The ATP is a pyrolysis technology for treating waste materials (such as soils) which contain mixtures of organic contaminants, water, and solids. These mixtures are economically and efficiently proc-

essed to produce separate by-products, which can be reused or disposed of in an environmentally safe manner. The process was originally developed by AO STRA and UMATAC to extract bitumen from oil sands and produce thermally upgraded oil. However, the process has since proven to have an additional capability in the area of hydrocarbon waste cleanup.

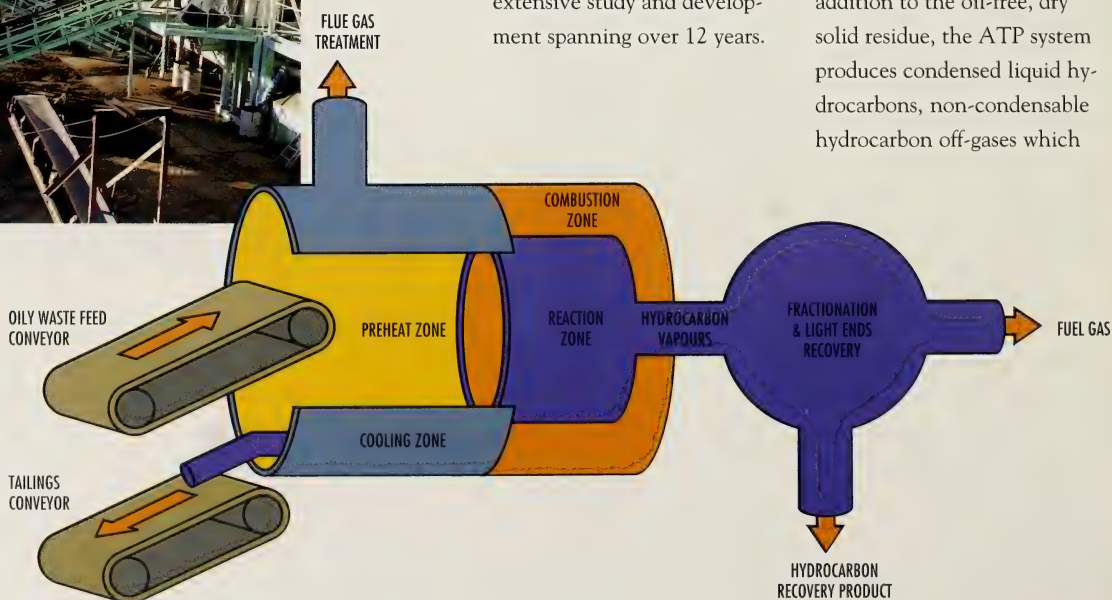
The Taciuk processor consists of a single, horizontal, rotating vessel, containing individual compartments or zones. In these zones, all the operations necessary for production of cracked, distillable oils from oily wastes takes place. The unique methods which the ATP uses to accomplish heat exchange, combustion, anaerobic pyrolysis, and interzonal sealing, required extensive study and development spanning over 12 years.

A 5 tonne per hour Calgary pilot plant has proven the effectiveness of the ATP in waste cleanup by successfully treating some 900 tonnes of widely differing waste material. These wastes included field tank and desand pit sludges, slop oils, spills, ecology pit mixtures, and waste drilling muds. In other tests, samples of flotation froth, slop oil emulsion solids, separator bottoms, and PCB-contaminated soils were processed successfully. In all cases, results of treatment in the ATP demonstrated total reclamation of oil-free, dry-host solids, which satisfied the U.S. Environmental Protection Agency specifications for clean landfill.

The ATP system is able to process feedstocks which vary widely in composition and physical characteristics. In addition to the oil-free, dry solid residue, the ATP system produces condensed liquid hydrocarbons, non-condensable hydrocarbon off-gases which



Oily waste solids are placed into hoppers where they are then fed into the ATP via a conveyor belt. The internal processes of the ATP are illustrated diagrammatically at right.



may be used as plant fuel gas, process water which can be treated or sent to disposal wells, and combustion flue gas which may require removal of particulates and, when necessary, sulphur dioxide. The processed solids, as indicated, satisfy specifications for disposal as clean landfill.

Considerable interest in the ATP has been generated within industry and with regulatory agencies, particularly since the first commercial, 10 tonne per hour, waste treatment ATP, purchased by Soil Tech Inc. of Porter, Indiana became available. Soil Tech will use this ATP unit for the contaminant separation portion of the Waukegan Harbour clean-up project in Illinois. It is expected that additional cleanup projects across the U.S. and Canada will be forthcoming.

AOSTRA is confident that this state-of-the-art technology will soon be in high demand and a key tool in the elimination of solid waste problems, not only in North America, but around the world. The ATP is an excellent example of the extremely effective partnership that AOSTRA has been able to achieve with the private sector in developing innovative and relevant technologies for the oil sands and other process industries.

In addition to the ATP, which has been a major development in the area of waste clean up and waste handling, AOSTRA has been involved in other research in this environmentally-important field.

Most processes, designed for the upgrading of bitumens or heavy crude oils, produce residual streams which must be utilized in an environmentally acceptable and economically feasible manner. It was for this reason that the AOSTRA/ Industry Upgrading Residue Utilization Study was initiated late in 1982. The participants included AOSTRA, Energy, Mines and Resources, and eight industrial companies. The study's objective was to identify, evaluate, and ultimately test the most promising technologies for the economic and environmentally acceptable utilization of residues, such as pitch or coke, produced during the upgrading of bitumen and heavy oil. The conclusions of the comparative study pointed to conventional combustion of the residue for use in steam generation, as the most economic disposal method.

A related issue in these residue utilization studies involves the minimization of production of upgrading residues. The reduction of residue can be accomplished most effectively by the adoption of high conversion hydrogen-addition

upgrading systems, in place of carbon rejection processes. The addition of hydrogen to bitumen in high pressure reactors would not only improve overall project economics, but would also sharply reduce the quantity of residues produced. Tests funded by AOSTRA, have paved the way for potential commercial use of such processes in Alberta, with their attendant reduction in the quantity of residue formed.

The 10 tonne per hour ATP unit depicted below, will be used in the cleanup of Waukegan Harbour in Illinois (note the "cleaned" solid tailings leaving the processor by conveyor belt).



CONVENTIONAL SURFACE MINING OIL SANDS PLANTS, USING THE HOT WATER EXTRACTION PROCESS, GENERATE ENORMOUS TAILINGS PONDS CONTAINING MILLIONS OF CUBIC METRES OF SLUDGE. THE BUILD-UP OF SLUDGE IN THE TAILINGS POND CONTRIBUTES TO THE INCREASING VOLUME OF MATERIAL WHICH MUST BE RETAINED. SLUDGE SOLIDS SETTLE VERY SLOWLY, REQUIRING MANY DECADES. METHODS ARE NEEDED TO CONSOLIDATE THE ACCUMULATED SLUDGE IN ORDER TO REDUCE THE VOLUME REQUIRING CONTAINMENT AND RECLAMATION.

Both Syncrude Canada Ltd. and Suncor Inc. have committed large amounts of money over many years to obtain an understanding of the dynamic behaviour of the tailings ponds and to seek a solution to the problem of sludge consolidation that is both technically and economically feasible.

In cooperation with these industries and independently, AOSTRA has also taken certain initiatives toward the development of methods for sludge consolidation and elimination.



AOSTRA and EcoPlastics Limited tested the performance of high molecular weight organic polymers for use as flocculating agents to precipitate suspended fine solids. And in 1978, AOSTRA and Xana Engineering Ltd. initiated the development of a method for the agglomeration of fine solids as a densified cake on the anode of an electrophoretic cell. Both of these technologies were abandoned because either the predicted advantages could not be confirmed by the experimental program or the estimated costs of commercial application were clearly too high.



CANMET's scanning electron microscope system; just one of the tools used in the characterization of sludge morphology.



In 1985, Syncrude Canada Ltd. and AOSTRA carried out a major field pilot program to test the feasibility of co-deposition of suspended solids contained in pond sludge, with dredged overburden. Experience in other unrelated dredging operations involving clay fines showed that during hydraulic transport in pipelines, the fines agglomerated into lumps which formed stable, trafficable deposits on discharge. The objective of the experimental program was to determine whether or not overburden removal by means of a cutter suction dredge operating in a dredge pond of tailings would absorb sludge with clay lumps to create stable overburden dumps. While the depositional behaviour of over-

burden dredged with "clear-water" demonstrated the formation of a stable, trafficable deposit, it was found that when a high solids content dredging medium was used, the deposited material was significantly weaker and was not trafficable. It was observed that the Pleistocene and Clearwater Formations behaved somewhat differently in terms of the stability of the dump with a high fines dredging fluid. Nevertheless the general conclusions of the test were not materially affected by the lithology of the overburden. Clearly a co-deposition approach would require isolation of the dump site.

The experience gained from the overburden dredging project has led to a further cooperative effort between Syncrude Canada Ltd. and AOSTRA, to carry out laboratory tests and a field pilot program to study the absorption of tailings sludge in dry-mined overburden. The resulting mixture of overburden and absorbed sludge, forming a soft clay of known shear strength, would be confined in polders or cells, constructed of unsaturated overburden material, and finally capped with unsaturated overburden to create a trafficable bearing layer. Geotechnical studies have shown the relationship of these sludge/overburden mixtures to be such, that waste dumps can be designed to meet current criteria for short and long term stabil-

ity. Preliminary estimates of the cost of poldering range between 25¢ and 50¢ per barrel of synthetic crude oil produced at the Syncrude plant. Development of the technology is continuing in an effort to determine the most effective method of mixing sludge and clay shale (overburden).

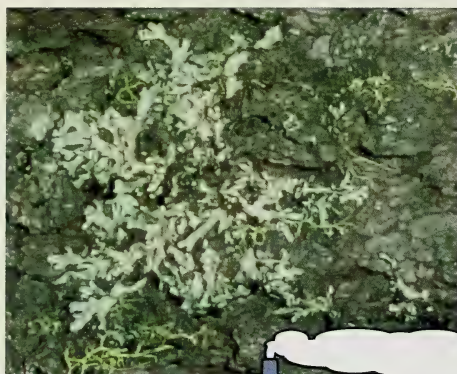
Recently, AOSTRA has joined with the Alberta Research Council, National Research Council, Energy, Mines and Resources Canada (CANMET), Alberta Energy, Syncrude Canada Ltd., and Suncor Inc., in a consortium entitled "Sludge Fundamentals." The objective of the consortium is to establish the fundamental properties of sludge by pooling the technical and financial resources of the participants. The results of the research will be shared among the participants, duplication of effort will be avoided and the exchange of technical information may trigger the generation of conceptual solutions to the problems of sludge consolidation, prevention of sludge formation, and sludge handling.

THE ASSIMILATIVE CAPACITY OF THE ATMOSPHERE CAN BE REGARDED AS A NATURAL RESOURCE WHICH MANKIND USES FOR THE DISPOSAL OF THE UNWANTED BY-PRODUCTS OF HIS ACTIVITIES. THIS AIR RESOURCE, HOWEVER, IS THE MOST PERSONAL OF RESOURCES, FOR EACH INDIVIDUAL DEPENDS ON IT TO LIVE.

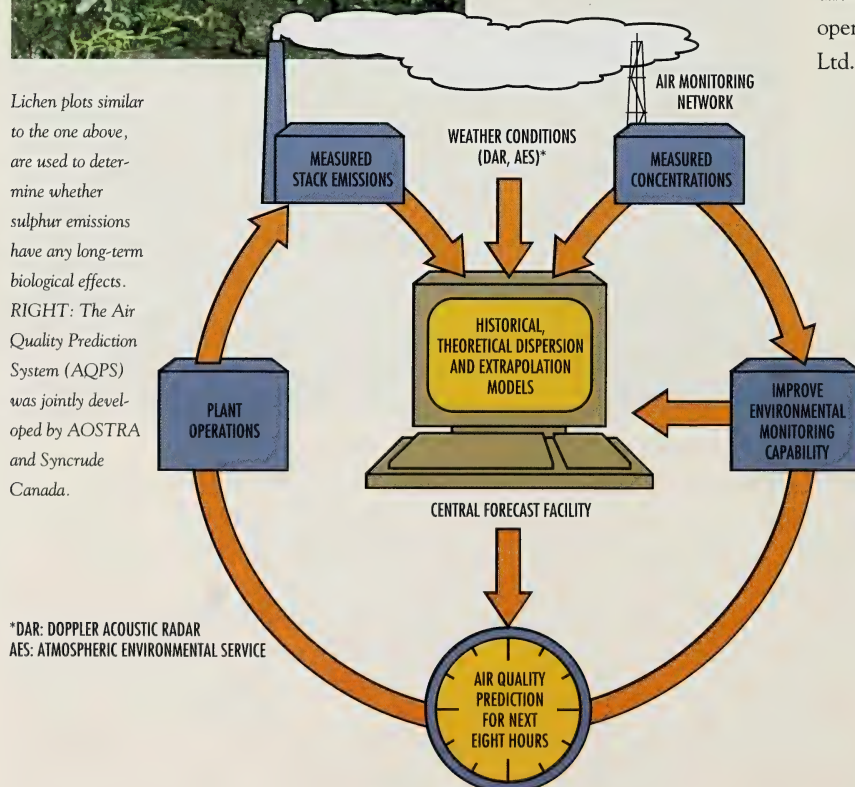
Consequently, responsible citizens, corporations, and governments everywhere must ensure that the quantities of pollutants emitted into the atmosphere are kept as small as best practicable technology will allow.

In 1982, Dr. E.C. Pielou, an AOSTRA professor at the University of Lethbridge, initiated an investigation into the

effects of sulphur dioxide (SO_2) on various plants. This work involved both field testing and controlled-atmosphere greenhouse experiments. The study was undertaken to determine the total biomass and productivity of aspen in the Fort McMurray area of northeastern Alberta. The objective was to relate biomass and productivity to air pollution from the oil sands mining and refining operations of the area. Air pollution from SO_2 and other mixed pollutants in the study area began to increase in 1967, associated with the start of operations at the Suncor oil sands plant. After 1975, emissions were further increased by the commencement of similar operations at Syncrude Canada Ltd.



Lichen plots similar to the one above, are used to determine whether sulphur emissions have any long-term biological effects. RIGHT: The Air Quality Prediction System (AQPS) was jointly developed by AOSTRA and Syncrude Canada.



*DAR: DOPPLER ACOUSTIC RADAR
AES: ATMOSPHERIC ENVIRONMENTAL SERVICE

The study found that pollution-caused damage to terrestrial vegetation in the oil sands region is slight to undetectable. Consequently, the information obtained by the study will be useful as baseline data, which can be used to evaluate the environmental impact of future oil sands projects.

In 1984, AOSTRA and Syncrude Canada Ltd. agreed to jointly fund a research project to develop a computerized Air Quality Prediction System (AQPS), which could forecast, up to eight hours in advance of real time, the possibility of air pollution exceeding the Provincial air quality standard. The system uses stack emission monitoring, a meteorological monitoring network, an air monitoring network, a central forecasting facility, and a man/machine interface for prediction/decision making. Once every hour, the AQPS forecasts air quality at each of five monitoring network stations, and allows the plant operator to predict the plume "footprint" and maximum sulphur dioxide concentration for a range of possible emission rates. Thus the operator can judge which strategy best meets a plant's multiple objectives of safe, reliable plant operation and maximum production with the least environmental impact. This system is available to third parties from AOSTRA.



Detailed characterization of flaring and stack efficiency requires both ambient monitoring, as well as occasional monitoring of the stack itself.

DURING THE PERIOD OF 1982 TO 1985 AOSTRA FUNDED A SERIES OF PROJECTS RELATED TO ASSESSING THE MUTAGENIC POTENTIAL OF BITUMEN AND CONVENTIONAL HEAVY OIL. THE MUTAGENIC EFFECTS OF OIL COMPOUNDS AND PETROLEUM PRODUCTS ARE OF INTEREST BOTH IN TERMS OF HUMAN HEALTH AND POTENTIAL ENVIRONMENTAL IMPACT.



Eric Peake and a technician prepare a sample for injection into an ion chromatograph. Characterization of the oil and oily water streams is essential to the assessment of their potential toxicity and mutagenicity.

With the financial support of AOSTRA, the British Columbia Cancer Foundation conducted carcinogenicity testing of oil sands process streams. Samples from various AOSTRA-supported pilot projects were assayed for their capacity to induce chromosome and DNA damage. The study was aimed at developing a relevant screening test for assessing potential human carcinogenic risk. Although the results indicated that some of the process streams could inflict genetic damage, the damage observed was only marginally above baseline levels, and weak when compared to reference carcinogens.

Also during 1982 to 1985, Professors Von Borstel and Mehta, at the University of Alberta, evaluated the possible mutagenicity of various process streams from in situ pilot projects. The AOSTRA-funded research identified specific aromatic hydrocarbons and terpenoids with mutagenic potential.

In addition, Mr. Eric Peake of the Kananaskis Center for Environmental Studies, at the University of Calgary, assessed the environmental hazards and human health risks that might arise from toxic and carcinogenic substances that could be generated during in situ fire-flood production from oil sands. Although mutagenic and toxic components of the produced oil were identified, caution must be exercised in the extrapolation of the results into a relative biohazard.

Much of the work in this field has concentrated on specific compounds, such as the polycyclic aromatic hydrocarbons, rather than synthetic oils or whole bitumen. The heavy oils of the Alberta oil sands contain organic compounds together with sulphur and nitrogen which, upon thermal treatment, have the potential to produce carcinogenic, mutagenic, and toxic components. Current technology for the measurement of mutagenic activity of specific compounds can be useful for oil fractions. However, until the biological activity of carcinogens in complex hydrocarbon mixtures is better understood, an accurate determination of whole oil mutagenicity cannot be made. Nevertheless, the findings of these studies indicate that further testing should be done, and that care should be taken in handling in situ combustion products.

THE DEVELOPMENT OF HYDROGEN TECHNOLOGIES, COVERING BOTH PRODUCTION AND UTILIZATION, IS SEEN AS ONE MEANS BY WHICH GLOBAL WARMING DUE TO CARBON DIOXIDE EVOLUTION FROM THE COMBUSTION OF FOSSIL FUELS MAY BE COMBATED. THE CONTRIBUTION OF THE OIL AND GAS INDUSTRY TO THE WORLD'S TOTAL GENERATION OF CARBON DIOXIDE IS OF CONCERN TO AOSTRA.

Much of the reduction in carbon dioxide emissions will probably be brought about through conversion to fuels which produce less CO₂ per unit energy, rather than the elimination of fossil fuels. Such fuels include natural gas and the lighter synthetic fuels. Processes which increase the hydrogen-to-carbon ratio of a fuel are in commercial use or at the demonstration stage for oil sands bitumen.

A total hydrogen economy may not be achieved in the foreseeable future. However, steps should be taken now to investigate the more efficient use of available surplus hydrogen in the production of transportation fuels from bitumen and heavy oil.

AOSTRA has joined with industry and other government departments and agencies in Canada under the umbrella of the Hydrogen Industry Council to expand research and development of hydrogen technologies on a broad front.

Finally, AOSTRA has initiated a program of environmental audits of all AOSTRA-participated projects, in order to ensure that established guidelines and permit requirements are being satisfied. The audits have resulted in several concepts for improved environmental management for some projects. AOSTRA has, in

addition, evolved an environmental action plan for the future, including:

- the identification and prioritization of environmentally-sensitive elements of concern within AOSTRA and the oil sands/heavy oil industry;
- the preparation of recommendations for the development of environmental programs;
- ensuring that AOSTRA projects conform to policy adopted by the Authority;
- the promotion of an awareness within AOSTRA of environmental activities being conducted by other governmental agencies and private industry.





RESEARCH &
TECHNOLOGY

IN 1974 WHEN THE PROVINCE OF ALBERTA FORMED THE ALBERTA OIL SANDS TECHNOLOGY AND RESEARCH AUTHORITY (AOSTRA), IT WAS RECOGNIZED EVEN AT THAT TIME THAT ALBERTA'S OIL SANDS COULD EVENTUALLY BECOME THE MOST IMPORTANT RESOURCE FOR THIS PROVINCE.

The resource, composed of mineable and more deeply-buried deposits of bituminous sand not unlike fresh asphalt, is present in sufficient quantity to provide paving for a four-lane highway encircling the world some 8000 times.

Even the most conservative estimates had indicated that the resource was nearly the largest in the world. Unfortunately, little was known about this vast reservoir of hydrocar-

bons except that it was in a much colder region and definitely more costly to develop than other resources.

Strip mining of shallow portions of the Athabasca deposit, as practiced by the Great Canadian Oil Sands Company (now Suncor Canada Ltd.) was economically feasible but this method was applicable to only about 10% of that deposit. Moreover, steam injection technology, as practiced in California and Venezuela, proved to be uneconomical, and gave disappointing results. Clearly, the skills or technology needed to develop the other 90% of the deposit profitably were untested or did not yet exist.

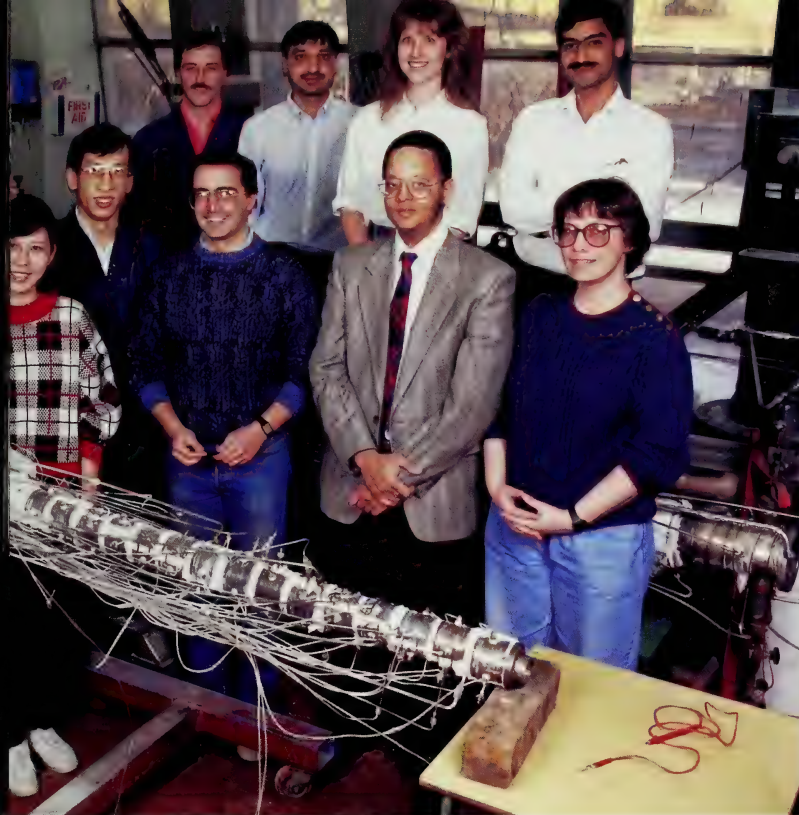
Some testing was being done but with each decrease in the price of oil, the testing would stop and the experts would leave. With another rise

in oil prices, testing would start up once more and with it the learning process. New experts would have to be trained and many of the earlier mistakes would be repeated.

This was a painfully slow and haphazard process which did not meet Alberta's economic imperatives. The province's economy was based to a

Farouq Ali participates in Simon Tortike's lecture on his theory describing flow of oil, water, and gas through an oil sands deposit. To solve the mathematical equations, very large, fast computers are needed, but the results indicate what experiments need to be done to enhance oil production.





Gordon Moore and John Belgrave, with their students, pose behind the high pressure combustion tube which was used to study ways to improve in situ combustion occurring as air or oxygen was injected into an oil sands deposit. The heat and CO₂ generated enhance flow of heavy oil to a producing well.

major extent on the production of light oil, a production that would decline predictably by a factor of about two every seven years. Such were the principal factors which lead to the formation of AOSTRA.

One of the first actions of the newly formed AOSTRA was to respond to serious concerns about the shortage of technical manpower and the need for specialized training facilities. Here it was recognized that many of the best minds in our nation are those of the professors at our universities. But they had to be

persuaded to re-orient their research interests along lines relevant to Alberta's needs and to teach the needed technical skills to our students. This was an extremely complex undertaking, and AOSTRA is very proud of the success that has been achieved.

The sobering reality in 1974 was that only about 10 professors and as many students were doing relevant research on the oil sands and little was being taught about this major field of knowledge. Now, more than 80 professors, all first-class researchers in science and engineering, are teaching and doing advanced research of direct relevance to Alberta's

great resource. Their laboratories are the best equipped in the world for this type of specialized investigation and their research reputations attract the finest students from Alberta and around the world.

More than 500 students have developed the needed special skills and obtained advanced degrees in the broad field of oil sands engineering and science. Most are working in Alberta's oil industry. Some are teaching. Their professors consult actively with their new colleagues in this important industry. This is how a technology-based society develops.

The professors and their students have achieved international recognition for the high quality and originality of their work. They have published the results of their research in internationally recognized scientific journals and account for more than 90% of such publications on Alberta's oil sands. They have formed their own companies to provide a much needed advisory service to industry and this influence is spreading internationally.



Loren Hepler, internationally known for his expertise in physical chemistry and methods of treating sludge from oil sands plants, is the longest standing member of the panel of peers. Here, his research associates describe a new experiment to measure heat generated by slow oxidation of bitumen.

Universities provide a special environment for doing experiments that test "radical" or innovative concepts. Evidence for this lies in the observation that most of Canada's patents and processes are based on research which began in universities. This is probably a direct result of emphasis on creativity in universities and the availability of graduate students seeking advanced degrees. Such challenges hone

the professors' skills to cut through the most difficult problems and quickly find useful solutions. In this effort they are soon matched by their students.

With financial and expert support from industry, AOSTRA allocates about one twentieth of its budget to funding research at universities in Alberta and the other provinces. Professors propose their best ideas for research. An independent panel of peers evaluates these proposals and AOSTRA allocates funds to those most highly ranked. The peers are all recognized leaders in research from industry and universities.

The projects are of one-, two- or three-years duration. Professors periodically report the progress in their research and assign ownership of their technology to AOSTRA. At the Technical Review Meeting and Seminar held each year in October, the professors and their students present the current results of their research. This year, 250 senior scientists and engineers from the oil industry, universities and government attended the meeting to learn about progress on some 65 oil sands research projects.

In the following pages, some of the many highly creative accomplishments of university research teams of professors and their students will be briefly described.

There is so much to tell. And here it should be emphasized that successful problem-solving involved new levels of cooperation among many intellectual disciplines. Let us begin by describing the fascinating geology of the oil sands, followed by some important advances chosen from physics, chemistry, engineering, and microbiology.



Stan Hall demonstrates the apparently magical effect that a very small addition of a soap or surfactant has on the viscosity of bitumen. The same cold mixture, 70% bitumen and 30% water, has been placed in each beaker. However, soap has been added to the one that flows freely. The intent is to develop ways of transporting bitumen by pipeline to convenient refineries.



Mike Ranger describes his research on the geology of a portion of the Athabasca deposit near Fort McMurray. With modern analogies in mind, he tells of evidence of a river estuary, 90 million years old, where sands shifting with the tides became buried in silt as the land settled beneath the Boreal Sea.

GEOLOGY

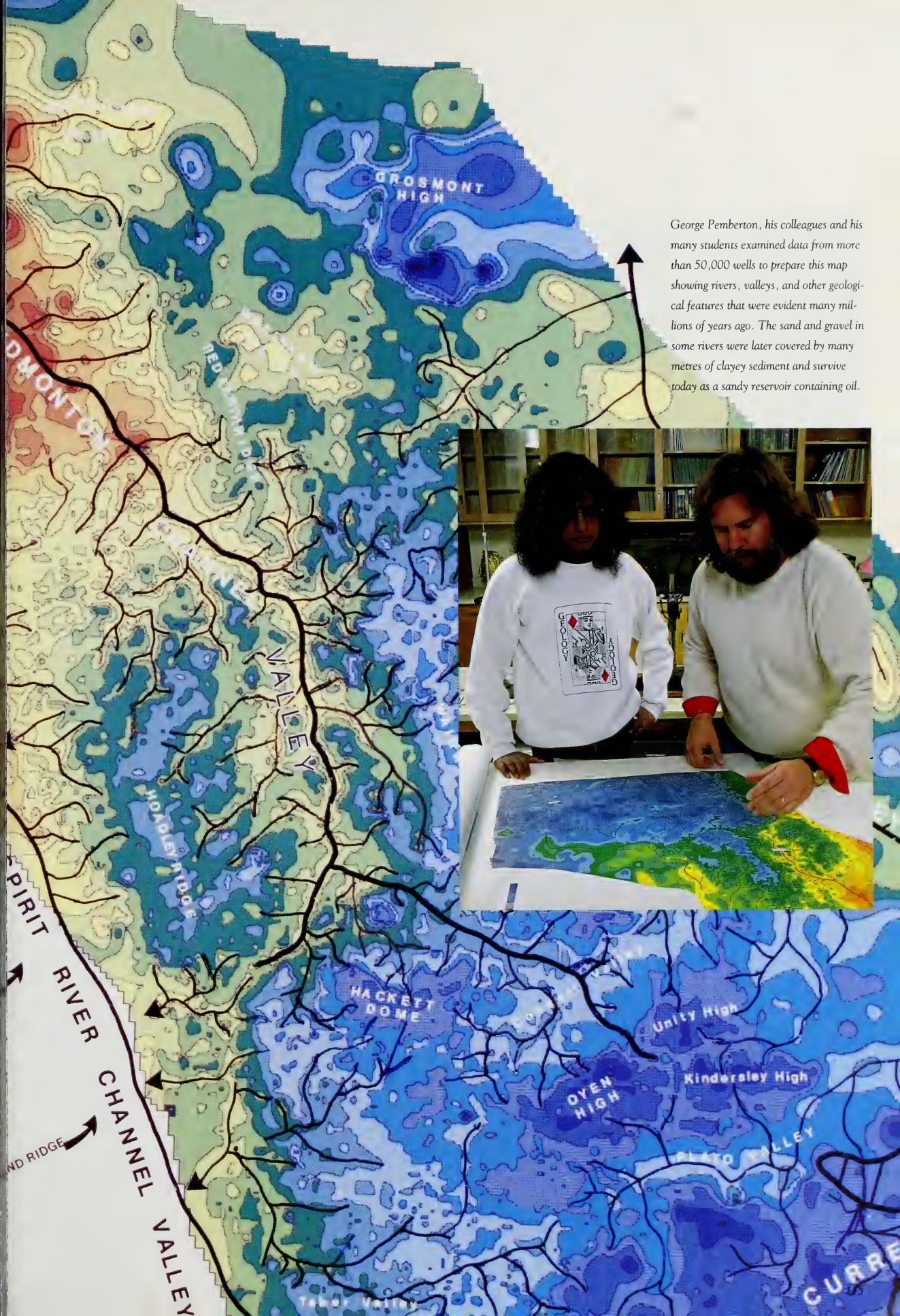
The geologist's view of Alberta is a profound one spanning many hundreds of millions of years. As the North American continent drifted westward, the rocky mountains began to grow and the granite rock that forms the base of Alberta began to settle. Through time and erosion, this granite was buried beneath many thousands of meters of sediment composed of layers of salty-water-filled dolomite, sands, shales and clays.

Geologists call these layers formations. They have described many of the formations, determined the age and extent of each and have provided names usually in honor of the location where the formation was first observed. This is the origin of such names as the Leduc and Grosmont dolomites, the McMurray sands, the Clearwater shales, the Viking sands and so on.

Here let us briefly describe some very relevant research studies by an Alberta Professor and his graduate students. The program involved gathering mineral matter, at various depths, from more than 50,000 oil and gas wells in Montana, Saskatchewan and Alberta with each sample being studied and cataloged by this research team. Their detailed examinations revealed, among other things, traces of wormholes in an ancient sea bed, clamshells, a reddish-colored clay, and many other vestigia. All are part of the "fingerprint" that the geologist uses to identify a change in the nature of the sediment. The picture that emerges is a fascinating one of remarkable alterations taking place in the fauna, flora and climate.

The results of this very comprehensive study have been published in the form of tables of data and regional maps. One such map shows, for example, that for a brief moment in geologic time, a very large river, called the Spirit River, flowed from Montana northward to the shores of a boreal sea near Fort McMurray. About 90 million years ago, the channels of this river became filled by fine sand and then were covered with clay and shale as the land fell slowly beneath the sea. Subsequently, oil seeped into it from underlying dolomite layers and remained trapped there. The success of tracing the path of this ancient river and others like it is important since such knowledge shows us where best to look for oil.

Recently, that is within the past fifteen million or so years, the land rose and was eroded by glaciers and water. What remains today is Alberta's and possibly the world's largest deposit of oil sands. This deposit is contained in the McMurray and Clearwater sands, exposed at the surface along the Athabasca River near Fort McMurray and along the Clearwater River nearby, and buried to a depth of about 600 meters near Cold Lake. For convenience the northern portion of this large deposit is called the Athabasca deposit and the southern portion is called the Cold Lake deposit.

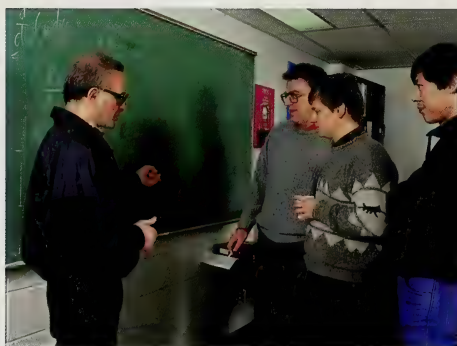


George Pemberton, his colleagues and his many students examined data from more than 50,000 wells to prepare this map showing rivers, valleys, and other geological features that were evident many millions of years ago. The sand and gravel in some rivers were later covered by many metres of clayey sediment and survive today as a sandy reservoir containing oil.





Ernie Kanasevich, his associate, and students discuss results obtained from novel seismic experiments done in the Clearwater deposit near Cold Lake. By producing noise deep in one well and listening with geophones placed deep in another, they learn how steam moves through the reservoir. In the foreground are the students' results of conventional seismic measurements of the deposit.



Famous Russian geophysicist, Vladimeer Markushkevich, describes a new seismic method of measuring the transmission and reflection of sound in the North Atlantic Ocean. Edo Nyland, his students and the visitor are designing an experiment to quickly measure the rate of settling and compaction of the many layers of sludge in the tailings pond of an oil sands plant.

GEOPHYSICS

Let us now examine an important method used to determine the extent of the oil sands deposits. The method is called seismic surveying. Here, the term seism means earthquake.

Geophysicists thump the ground with little explosions and create small or micro-seisms. They listen with geophones – a type of microphone – to the echoes bouncing to and from the surfaces of the many layers of sediment below. In principle, the method is similar to that used by a bat to determine its distance from the floor in a room.

Knowing the speed of sound in each of these layers, the geophysicist determines the depth to each layer within plus or minus 50 meters and whether the layer may contain gas or

oil. Now, with the advent of high speed computers and more powerful mathematical programs, novel methods have been developed in Alberta to determine not only the thickness and extent of a layer but what is happening in that layer.

Laboratory studies have shown that the velocity of sound through oil sand may be reduced by as much as 25% if the sand is heated. This is an important change of velocity. Not only does the sound slow down as it enters a heated portion of a formation, but it also changes direction or refracts. The manner of refraction is similar to that of light as it slows and refracts on entering water.

These new laboratory measurements, and their predictive models, show great promise as an application in the field to estimate the extent that a formation has been heated by steam or by combustion.

It would obviously be of great importance to be able to see what is happening in the formation as we inject fluids to produce oil. However, since direct visual observation is not feasible we must do our best with other methods. There follows a description of one of these methods developed recently.

The formation is a very noisy place. When it is heated or fluids are injected into it, it swells, creaks and crackles. The noise is made by many very



Doug Schmitt prepares his "down-hole" televiwer for field testing. This unique device uses high frequency sound to "see" through the drilling mud and into that portion of the deposit nearest the well. The results may indicate the direction in which rapidly injected water will fracture the deposit. By means of such fractures and suitable wells placed nearby, the production of oil could be markedly enhanced.



Edo Nyland, Doug Schmitt, and a student discuss exciting, new results from a steam-injection pilot south of Fort McMurray. Sounds generated by steam heating the deposit 350 metres below are seen on these recordings from widely spaced geophones. Careful analysis using large, fast computers will show that the sounds are generated near those portions of the oil sands deposit being heated most rapidly by the injected steam.

small earthquakes, called microseisms, that occur in or near the path taken by the injected fluid. Recently, a promising new technique to locate these microseisms has been developed.

Special geophones with microphones sensitive to low frequency sounds in the earth, are used to "listen" to these noises. However, listening is not as simple an exercise as it may seem.

First, the sound registered at each geophone is recorded and timed so that it may be compared with that registered at other geophones that are tens of meters away. Then, these sounds are interpreted by

a very clever computer that identifies the voice and tone of each noise as it is registered and points to the place from which the sound comes.

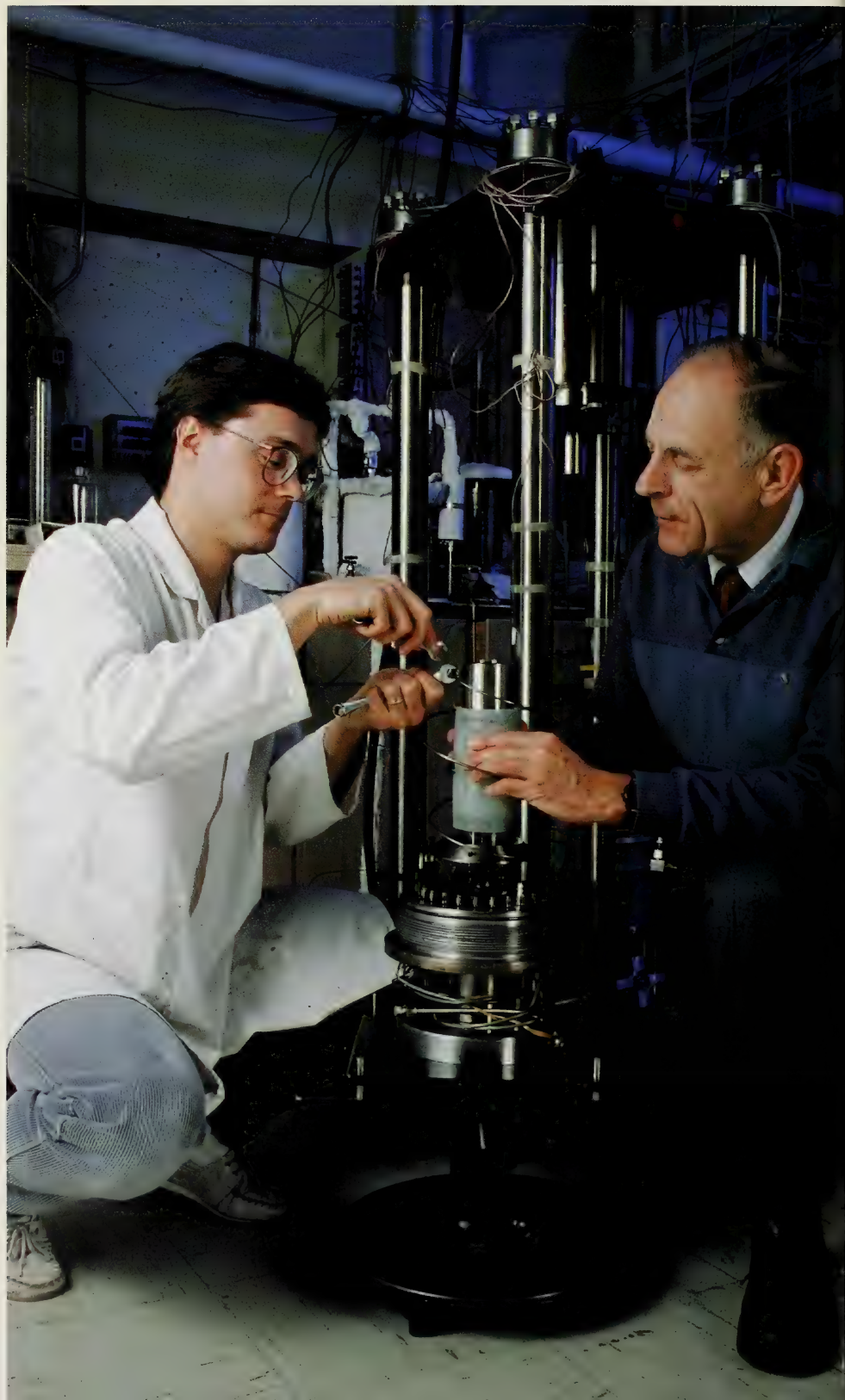
Sound familiar? This geophysical technique was undoubtedly suggested by our ability to listen with our two ears to one person speak in a noisy crowd. We identify the voice and its direction and listen to what it tells us. Here the "computer" which processes the information is our brain.

The computer is of course nowhere near as complicated as our sensory system. However, the computer must correct for the many echoes that occur and for variations of

velocity of the sound as it passes through sand, shale and clay, all wet and hot or cold.

Microseisms are generated also by a drilling bit as it is pushed into the ground. In some production methods it is important to determine quite accurately the distance from one well to another. So it is with a method that employs two horizontal wells, one nearby above the other. Geophones placed in one well already drilled can be used to "listen" to and guide the drilling of the other well.

Don Scott and Rick Chalaturnyk prepare their "triaxial cell" that applies high pressures from three directions to a sample of oil sands. They will measure changes in the permeability of the sample to hot water and additives. Major parts of Alberta's deeply buried oil sands contain smectite clays that when immersed in hot water or steam expand to plug the pores through which the oil must flow.



CIVIL ENGINEERING

Civil engineers have carefully measured the level of the surface of the earth above formations into which large volumes of water or steam are being rapidly injected. The surface appears to "balloon" upward in certain characteristic patterns that suggest that the formation may have been split or fractured. That is, the injected fluids have pushed aside sand to create fissures, or fractures, as they are termed.

There is a strong incentive to develop models that describe or predict the direction and rate of growth of these fractures. Other experiments show that if properly placed, such fractures can very significantly increase the rate and production of Alberta's heavy oils and bitumens since they can provide paths through which the oil can flow to the production wells.

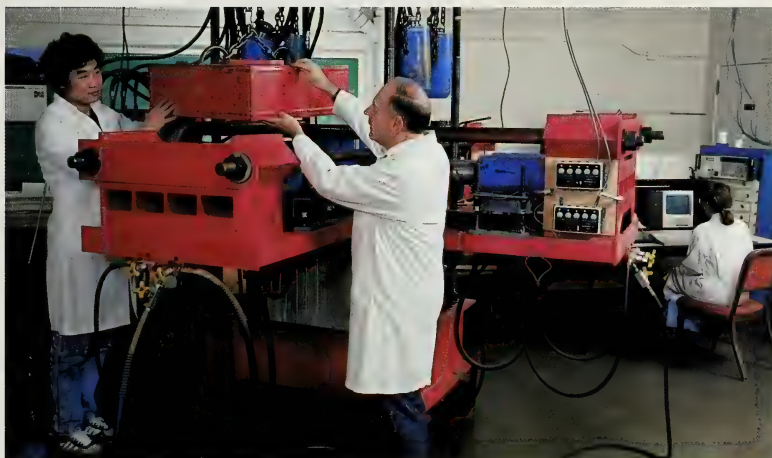
The concepts are simple but the models are not.

First, let us consider the stresses and strains in an oil-bearing formation. One stress on a formation is the pressure applied to it by the weight of all the sediment lying above it. We call this overlying sediment the overburden. If the overburden is not too thick, say less than 400 or 500 meters, then it is easily lifted by fluids injected rapidly in large volumes. The large fractures so created travel horizontally for a short distance then climb at first slowly then more and more rapidly up to an overlying layer of shale that is not easily broken, or even to the surface. However, if the overburden is

deeper than about 600 meters, fractures take on the form of large vertical cuts through the formation, subtended above and below by shales and clays.

The physical processes that govern the path and rate of growth of these formation fractures have been studied and modeled in our laboratories. The models have predictive capability and have been confirmed in field tests. Control of these pathways is most important since if they are well placed, oil production can be increased significantly. Such experiments have been of immense value to commercial operations.

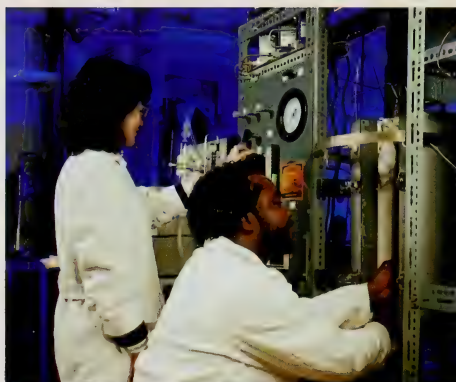
Don Scott and his students are preparing this triaxial cell, possibly the largest in the world of this type, to measure the strength and fracturing of a large block of cemented sand. The temperatures and pressures applied are similar to those that occur when a deeply buried deposit is steamed. The results will be used to test their novel theories that may be capable of predicting how an oil sands deposit will fracture and whether the fracturing can be controlled.





LEFT: Karlos Muehlenbachs and his students are separating components of heavy oil that has been thermally cracked in the presence of hydrogen (called "hydrocracking"). From the measured concentrations of certain isotopes such as carbon and sulphur they determine mechanisms of reaction for a novel refining process that may become commercially important. The objective of this experiment is to determine whether Alberta coal may be mixed with heavy oil to increase the yield of gasoline, diesel fuel, and other products.

ABOVE: Murray Gray and his students are doing experiments that show the mechanisms by which certain components found in heavy oil are hydrocracked. He is having great success using his novel theories to predict results obtained by hydrocracking mixtures of these components. Such theories are important to the development of new processes and solving problems of existing ones. RIGHT: Jim Hyne and his students are improving a process that reacts bitumen with water in the oil sands deposit. This novel process, called "aquathermolysis," is now patented. Certain chemicals are added to the steam that is used to heat a deeply buried oil sands deposit. Some large molecules in the heavy oil react with the chemicals and water to produce small molecules. The small molecules tend to reduce the viscosity of the heavy oil. Pilot scale tests are planned.



LEFT: Nosa Egiebor and a student are developing their novel process that uses certain gases at "supercritical" conditions. At such high temperatures and pressures, the gases can be used to selectively purify valuable compounds contained in heavy oils and bitumens. A similar process is used to remove caffeine from coffee.

HEAVY OIL AND BITUMEN RESEARCH

University research groups, with AOSTRA support, have made extensive measurements of the properties of bitumens, heavy oils, and oil sands. Here, let us describe some of these properties and why their measurement is so important.

What is a heavy oil? It is much darker in color, nearly black, and many hundreds of times more viscous than the light oil that now fills the pipe-

lines to eastern Canada and the U.S.A. However, if we simply allow the more volatile components, that is the smaller hydrocarbon molecules, to evaporate from a light oil, the residue has the appearance and consistency of heavy oil. Careful chemical analysis shows, however, that while there are many similarities between the two materials, marked differences exist because of their different geological histories.

Bitumen is simply extremely heavy oil. In the following paragraphs, the terms, heavy-oil and bitumen will be used interchangeably.

Heavy oil is much too viscous to pump through the pipelines mentioned above. Furthermore, the molecules in it are too big and have boiling points too high to be of much use in making the refinery's main product, gasoline. Therefore, special equipment, not always available in the conventional refinery, is used to heat the oil to more than 450°C to break up or "crack" the big molecules into smaller ones. The final product resembles light oil and is called synthetic crude or "syncrude".

New separation methods developed in our laboratories show that heavy oil contains tens of thousands of compounds. Through painstakingly detailed studies, a significant fraction of this myriad of compounds have been analyzed and their molecular structure established. From the understanding gained about the reactivity and solubility of these compounds, new refining processes can be much more readily developed. Two novel processes that produce no coke and higher yields of lighter liquids have been invented at the Alberta Research Council directly as a result of these analyses.

At Alberta's two oil sands plants near Fort McMurray, bitumen is not easily extracted from some of the mined sands. This is a costly problem since it is not evident, by simple observation, which mined sand cannot be processed. Samples of these intractable sands have been analyzed and although they are rich in bitumen, these sands contain also some molecules that cause the bitumen to bond strongly to sand. Many of these bonding molecules have been identified, thus providing a basis for solving this important industrial problem.

From detailed data generated in laboratory experiments at universities, new computer programs have been written that successfully model the distillation of heavy oil and the viscosity and density of its fractions. With such programs it is possible to design accurately in a few hours most of the processes which occur in a refinery. This is a task that once required years to accomplish. One professor and some colleagues from industry have developed a thriving company in Alberta that sells such computer programs internationally. Another academic entrepreneur now operates a very successful company that simply measures the physical properties of bitumens and heavy oils.



Bill Svrcek and his colleagues recently developed and now sell an inexpensive computer program, "HYSIM," capable of modelling all processes found in a refinery. Most undergraduate students of chemical engineering now use this program to design petrochemical plants and refineries. The program is "user friendly" and is popular with professional engineers in Canada and the U.S.A. It is based on theories and equations developed recently in Alberta by Don Robinson and Dinyu Peng.



Norman Wardlaw and his students developed a novel computer program that rapidly plots the outline of pores that are seen in photographs of a thin slice of a small sample of oil sands or of oil-bearing sandstone. Another program determines which pores are important for production of oil.

Anil Mehrotra is preparing a cell to measure at high temperatures and pressures the solubility of certain gases in heavy oils and the viscosity of their solutions. The data generated by these experiments and the mathematical correlations describing these data are in great demand by industry.



PHYSICS

Grains of sand are fairly irregular in shape and do not pack well together. The spaces between the grains of sand are called pores. These pores account for about 25% of the total volume of the sand. It is in these pores that we find heavy oil, salty water and sometimes some gas.

If the pores are 100% full of oil then it is said that the sand is 100% saturated with oil. However, it is rare for such high saturation to be found

even in the richest sand layers. The water is not distributed evenly about a pore but finds itself spread thinly over the surface of the sand grains ("water-wet" sand) or in the center of the pore ("oil-wet" sand).

When viewed under the microscope, it is seen that fluid must be pumped into a sand to wash out or flood the oil out the other side. However, the physical and chemical processes that occur are not well understood. For example, the oil and the water may move in the same or in opposite directions. Over the past 15 years much has been learned about these processes and it appears very probable now that the classical models describing fluid flow may be incorrect, especially for small scale calculations. New models have been developed taking into account current knowledge of these systems.

Oil production itself is affected by many variables, including, temperature, saturation, how much of the sand is oil-wet, the viscosity of the oil, and the geology of the sand. With so many factors to consider, it is easy to understand why operators find these models essential for optimal production of bitumens from an oil-bearing sand.

Let us now outline briefly some novel oil-recovery processes developed from insights obtained from studies just described.

LEFT: Norm Wardlaw and a student are doing experiments that model the mechanisms of oil production as water is pushed through an oil sands deposit. One important mechanism studied here shows water and oil moving in opposite directions through the sand. This and other significant mechanisms are not yet incorporated into the large computer programs that are used to optimize commercial production of oil. The two students seen in the background are measuring the effects of certain chemicals on forces by which water and oil adhere to or wet the sand. Oil is not easily produced from sand that is wetted by oil.



Bill Costerton and Francene Cusak use a controlled environment to prepare cultures of "pseudomonas" bacteria found commonly in soils. Successive generations of these bacteria become smaller, shrinking by a factor of a hundred from their normal size of a few millionths of a metre. These bacteria, now too small to be seen under a microscope, are mixed with some nutrient and then are easily transmitted to selected portions of an oil sands deposit. There they grow and plug the pores. Their process is now patented and pilot-scale tests show encouraging results.

BACTERIAL METHODS

More than 50% of Alberta's light oils are produced by "water flooding". The method is an old one. Clean water is injected at one or more wells to push the oil through the reservoir to nearby production wells. There the oil is pumped to the surface.

Experience shows that the water manages eventually to find a short-cut channel through the oil to a producing well. Commonly, the oil is much more viscous than the water. In such a case, the amount of water produced each day soon exceeds by far the amount of oil produced and the cost of pumping becomes too high. There is little that the operator can do but shut down the well and drill another.

Recently, our microbiologists recognized that some bacteria may be mixed with the injected water to plug the channel and cause the water to find another path to the producing well. The secret was to select bacteria and condi-

tions that would locate the plug at the best place along the channel.

Some bacteria, such as pseudomonas, which is found everywhere in the soil, become very small when starved. Their size is reduced to much less than one micron (one millionth of a meter) and hence they are called "ultra-micro" bacteria.

These ultra-micro bacteria have a special property: when mixed with an appropriate food, they do not begin to grow until a predictable time has passed. This time may be selected to be one or two months. The bacteria are now small enough to be carried freely along the same path taken by the waterflood described above. There, after the predetermined time has passed, the bacteria adapt to the food, adhere to the sands in the reservoir and begin to grow. As they grow, they produce a slime that fills the pores and hinders further passage of water along this channel.



A subsequent water flood therefore must find another path to reach the producing well. The effect is that the amount of oil produced suddenly increases and the amount of water produced decreases.

This method of using ultra-micro bacteria has been tested in large vessels in our university laboratories. The results are encouraging. Field-pilot trials are planned for the near future.

Phil Fedorak and a colleague are preparing cultures of bacteria that digest some of the sulphur contained in the large molecules found in heavy oils. Since such sulphur binds together parts of these large molecules, the product is a much lighter, easily flowing oil. Currently, their process is too slow to be commercially significant. However, it is possible that some of these bacteria may be injected into currently unimportant oil sands deposits to slowly produce light oils for future generations.



LEFT: Farouq Ali and two of his students develop and test novel methods of producing heavy oil from deposits in which the oil is found at the top and water at the bottom. Such deposits are common in Alberta. Here, an experiment is being prepared to observe the effect of injecting a small quantity of gas at the water-oil interface. Since the oil is viscous, it is not as easily displaced by gas as is water.

RIGHT: Ayodeje Jeje and one of his students are doing an experiment that models Syncrude and Suncor's tumblers which mix oil sands and hot water to produce a slurry. Here, the large tank had been filled with water and small plastic beads had settled to the bottom. Upon starting the propeller and injecting steam at the bottom, everything became mixed. From careful measurements of the streamlines and turbulence in the tank, optimal design and operating conditions may be derived.

Other university researchers have shown that if a waterflood is halted briefly while a small quantity of carbon dioxide is injected, then the carbon dioxide slowly dissolves in the small droplets of oil that are in the channel described above. These droplets swell and form a stable emulsion that hinders further passage of water through this channel. This novel process for directing the water drive into oil-rich regions of the reservoir will be tested soon in a semi-commercial pilot in Alberta.

Very extensive research is being done in the U.S.A. and Canada with water-soluble polymers that are being injected to hinder further passage of water through the short-circuit channel described above. The procedure appears to be simple and to hold great promise. However, the polymers are costly and the results from field pilots are disappointing. Fortu-

nately, our university professors have developed models with predictive capability. With these models it is evident now that the methods tried in field pilots were not optimally designed. Much experimenting with these models is being done to determine the conditions for best performance.



ABOVE: Two of Farouq Ali's students do experiments to determine how certain soaps and surfactants improve the efficiency of a waterflood. Some of the soaps are remarkably effective. However, careful economic analysis by his students show that they may not yet be commercially attractive. Nevertheless, as understanding improves, the target nears.





LEFT: Farouq Ali and two of his students are preparing an experiment to test his novel improvements to the waterflood process. The waterflood is halted briefly while a small quantity of carbon dioxide is injected. Under certain conditions, an emulsion is produced to divert the waterflood to other, richer, portions of the deposit.

DREDGING

Laboratory experiments show that when lumps of clay are mixed with fresh water, the clay is rapidly dispersed into the water. However, if the lumps are mixed with sludge from the waste water of an oil sands plant, the lumps remain solid. This is important. With this sludge, dredges can be used to remove the clay and silt that are now being mined from above the tar sands.

Dredging is one of the least expensive methods of moving dirt. It is much less costly than the trucks, draglines, excavators and other equipment now used to mine the overburden. However, if the clays are dispersed, then the result is a very large and expensive tailings pond.

Encouraged by the findings in these laboratory experiments, AOSTRA and Syncrude Canada Ltd. transported a dredge to a site near Syncrude's plant and demonstrated that dredging of overburden is feasible. It seems reasonable to conclude that the success of these experiments also encouraged another company to do pilot tests to determine the feasibility of dredging of oil sands. Perhaps the next oil sands plant will use dredging to reduce the cost of oil sands removal.



ABOVE: Peter Clark and a student demonstrate their novel process that uses very high frequency sound or "ultrasound" to thermally crack heavy oils. The energy of the sound is so intense that the device must be placed in a sound-proofed enclosure. When applied to mixtures of water and heavy oil, the viscosity of the oil is greatly reduced. LEFT: Jacob Masliyah and his students prepare an experiment to measure the effect of spraying clean water onto the oily froth that floats to the surface as air is injected into a slurry of oil sands and water. They are pleased that their theories, now well tested by these and other much larger experiments, may be used to improve the efficiency of the hot water process currently used commercially near Fort McMurray.

STEAMING

For oil-bearing formations that lie too deeply to be mined, steam may be injected at high pressures, say 100 atmospheres, sufficient to displace some oil and penetrate far into the sand but not so high that the nearby formations are fractured thereby allowing the steam to escape. This process is called "steam-assisted production".



ABOVE: Roger Butler and a student prepare an experiment to test methods they have recently developed for improving the operation and design of horizontal wells. Before filling the cell with oil sands and injecting steam, they examine one of the many thermocouples used to measure temperatures. LEFT: Gordon Moore and his students prepare an experiment to measure the heat generated by the incomplete combustion and polymerization of oil that occur at temperatures lower than about 350° C. There is a great deal to learn but the economic return to Alberta will be enormous if the in situ combustion process can be made to work predictably well.



In a commercial operation, many thousands of tonnes of water may be heated to 300°C then injected over a period of several weeks. In this way a large volume of the oil-bearing sand may be heated. At these high temperatures, oil is less viscous and flows rapidly to a producing well. This process works well in California, but not so well in Alberta where the formations are very much colder.

Another method of heating the oil-bearing layer of sand is to inject air and cause some of the oil to burn. The heat generated is carried along with the spent gases and steam, away from the well where the air is injected towards a nearby one where oil is being produced. This method, called "in situ combustion" is an old one. However, its application is not simple and fraught with difficulty. Nevertheless, the method can be made to work and has good potential to economically heat thin formations.

Large strong vessels are used in the laboratory to test this method. The vessels are filled with samples of wet oily sand obtained from formations. Then, air and gas are injected at high pressure at one end of the vessel and are ignited there. Flue gas, rich in carbon dioxide and steam, exits at the other end of the vessel.

After a few minutes, the gas is shut off and only air or a mixture of air and water is injected. If combustion continues unabated, and hot oil is pushed along in front of the flame toward the other end of the vessel, then the method has promise of being applied commercially. In this manner, the risk of using it commercially has been reduced to acceptable levels. Now, similar tests are being done in the industry.

Recently, researchers have determined that if the flame front smolders, "goes out" or dies, a chemical reaction differing from combustion occurs. The oxygen in the injected air reacts with the oil to produce soaps and other oxygenated chemicals. These chemicals cause the oil to become as viscous as axle grease. Unfortunately, it is not easy to avoid this condition of "low temperature oxidation".

Are there any advantages to injecting oxygen rather than air? Laboratory experiments show that the answer is a qualified "yes". Recall that 100 m³ of air contains about 21 m³ of oxygen and 79 m³ of nitrogen and that it is the oxygen that sustains combustion; the nitrogen is relatively inert. In practice, we find that it is more expensive to compress large volumes of air than it is to first separate the oxygen from the air then compress the oxygen.

With this thought in mind, researchers have carried out many experiments using the equipment described above to determine whether there were disadvantages and found, to the contrary, that for sands containing heavy oil, there are additional advantages other than the obvious one of cost. One problem of injecting air is that there is not always an easy path for the nitrogen-rich flue gas to exit the formation.

Laboratory experiments show that if pure oxygen is injected into a portion of the formation that has been heated previously by steam, then combustion occurs without the problems of low temperature oxidation described earlier. The carbon dioxide produced by this combustion is fairly pure and on finding its way to portions of the formation cooler than about 31°C, it condenses to a liquid.

Now, things become interesting. Experiments show that this carbon dioxide dissolves in the heavy oil, markedly decreasing its viscosity. If subsequently, the pressure of the formation is allowed to drop much below 650 kPa, then the dissolved carbon dioxide begins to boil out of solution and with it the heavy oil will foam into the heated portion of the formation and thence to the production well. This model, derived in the laboratory, appears to describe fairly well what is now being observed in commercial operations.



ABOVE: Gordon Moore and students prepare an experiment to determine whether a certain oil sands deposit is a good prospect for in situ combustion. Oil sands are packed into the long reactor. Air or oxygen is injected into one end and flue gas exits at the other. The many measuring devices and heaters are intended to provide conditions that simulate those found in an actual deposit. LEFT: Leslie Barta and a student use a very sensitive calorimeter to accurately measure the heat generated by in situ combustion of oil sands. With Loren Hepler, they have shown that in situ combustion works best with nearly pure oxygen being injected into a deposit that has been steamed. Another application of their calorimeter was to measure the effects of certain additives on the rates of settling and compaction of oil sands sludge.

RIGHT: Steve Chute and students prepare an experiment that tests a novel process using high frequency electromagnetic radiation to heat an oil sands deposit. Based on their many careful measurements of the effects of such radiation on small samples of oil sands, they designed this special "traveling wave" antenna that is about to be tested. BELOW: Fred Vermeulen and his students show a section of their specially-insulated steel casing that will be used to electrically heat an oil sands deposit. Their unique process is being patented and has special application for deposits too deep to be mined but too shallow for steaming.



ELECTRICAL HEATING

An electrical current may be used to heat an oil-bearing formation. However, large scale pilot tests in Alberta have provided disappointing results. Subsequent experiments, at our universities, show that the electrical resistivity of a sample of oil sands is strongly dependent on temperature and on the frequency of the current. A model was developed to describe electrical heating and flow of fluids for various



RIGHT: Eric Tollefson and his associate do experiments to determine how bituminous pitch from another process might affect operation of a fluid coker such as the world's largest one used by Syncrude Canada Ltd. Other experiments are also being done in this laboratory including a process that economically removes sulphur from waste coke so that it can be burned cleanly; a process to economically remove hydrogen sulphide from the small quantities of natural gas that may be produced by isolated wells; and additives that may be mixed with heavy oil and some water so that the mixture can be transported easily by pipeline.



arrangements of electrodes placed in the formation. With such a model, an optimal placement of electrodes and mode of application of current became evident. This novel process is being patented.

ENVIRONMENT

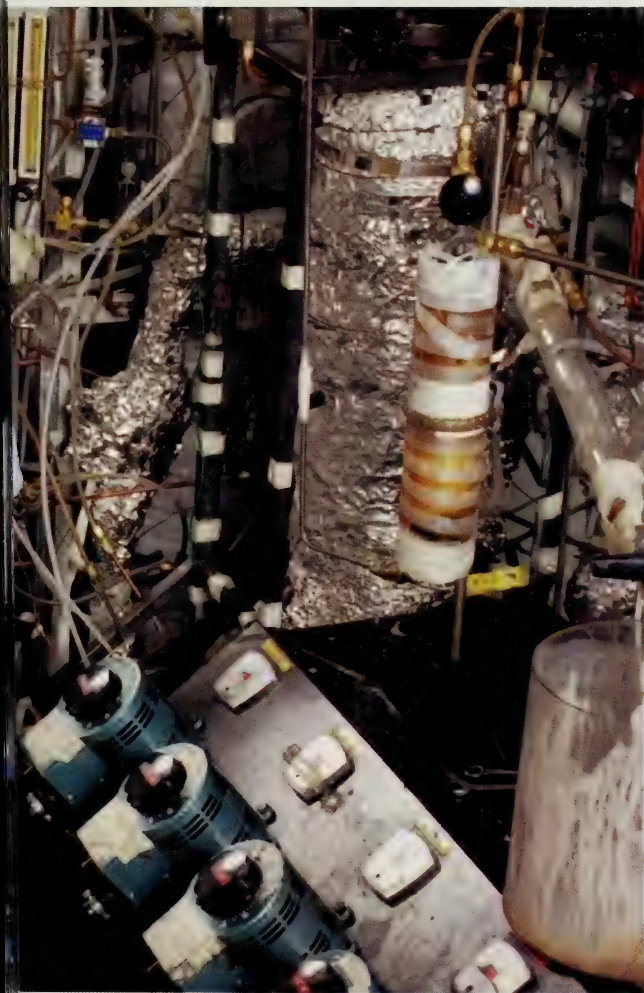
One of the mandates of AOSTRA is to ensure that technology developed under its sponsorship is environmentally acceptable. Although other government departments have

the responsibility for setting limits for materials released to air, waters, and land, and for undertaking research on the effects of various contaminants on the natural environment, AOSTRA is required to develop processes which will safely meet such limits.

AOSTRA sponsors a great deal of research of a general nature, which relates either directly to the protection and enhancement of the environment, or indirectly to the

reduction of environmental impact. This research is sponsored partly at Canadian universities and research institutes, and partly in cooperation with industry. What has been achieved in these programs is described in the "Environment" section of this Portfolio.

BELOW: Nosa Egiebor and Joshua Otaigbe developed a unique process for combustion of petroleum coke. Such coke contains a great deal of sulphur and is an important waste product from existing commercial plants near Fort McMurray. If burned in a furnace, unacceptable quantities of noxious sulphur dioxide are emitted. However, this coke can be made into a valuable fuel by mixing it with limestone and other inexpensive chemicals.



DURING THE PAST 15 YEARS, THE NATURE OF OIL SANDS AND HEAVY OIL RESEARCH IN ALBERTA HAS CHANGED CONSIDERABLY. BACK IN 1975, WHEN AOSTRA WAS JUST GETTING UNDERWAY, THE DEVELOPMENT OF TECHNOLOGY TO EXTRACT BITUMEN FROM DEPOSITS THAT COULD NOT BE REACHED BY SURFACE MINING WAS IN ITS INFANCY.

About all that was known for certain was that the steam injection technology used to recover heavy oil was inadequate for recovery of the much more viscous bitumen from Alberta's oil sands deposits, and thermal recovery techniques that had been successful in recovering bitumen in California, had given disappointing results when used in Alberta.

Thus began a quest for a better understanding of the Alberta oil sands and heavy oil resource, and a substantial research program was launched by AOSTRA to find cost-effective ways to recover and use these resources. The net result of all this effort was the establishment at the Alberta Research Council (ARC) of a centre of excellence for oil sands and heavy oil research that is second to none. Whereas research of this kind was virtually unheard of in 1975, today in Alberta's universities, students graduate each year with expertise in oil sands and heavy oil research, and AOSTRA's Institutional Research Program activities at ARC have become not only the key centre for research of this kind in Alberta, but in the world.

Much of this research involves substantial funding and a long-term commitment, with no guarantees that the financial investment will pay off. Therefore, it is not the type of research activity that industrial laboratories are best suited to undertake. On the other hand, government-funded laboratories tend to become involved in projects having a larger social purpose. Thus was born an oil sands and heavy oil research centre of excellence, funded primarily through AOSTRA, but also supported by industry.



These cores were recovered from deeply-buried deposits using special hollow drilling bits. They show the many layers of clay, silt, sand, and other sediments that may contain oil. Geologists are examining these cores from the Underground Test Facility project site for detailed characterization of the reservoir.



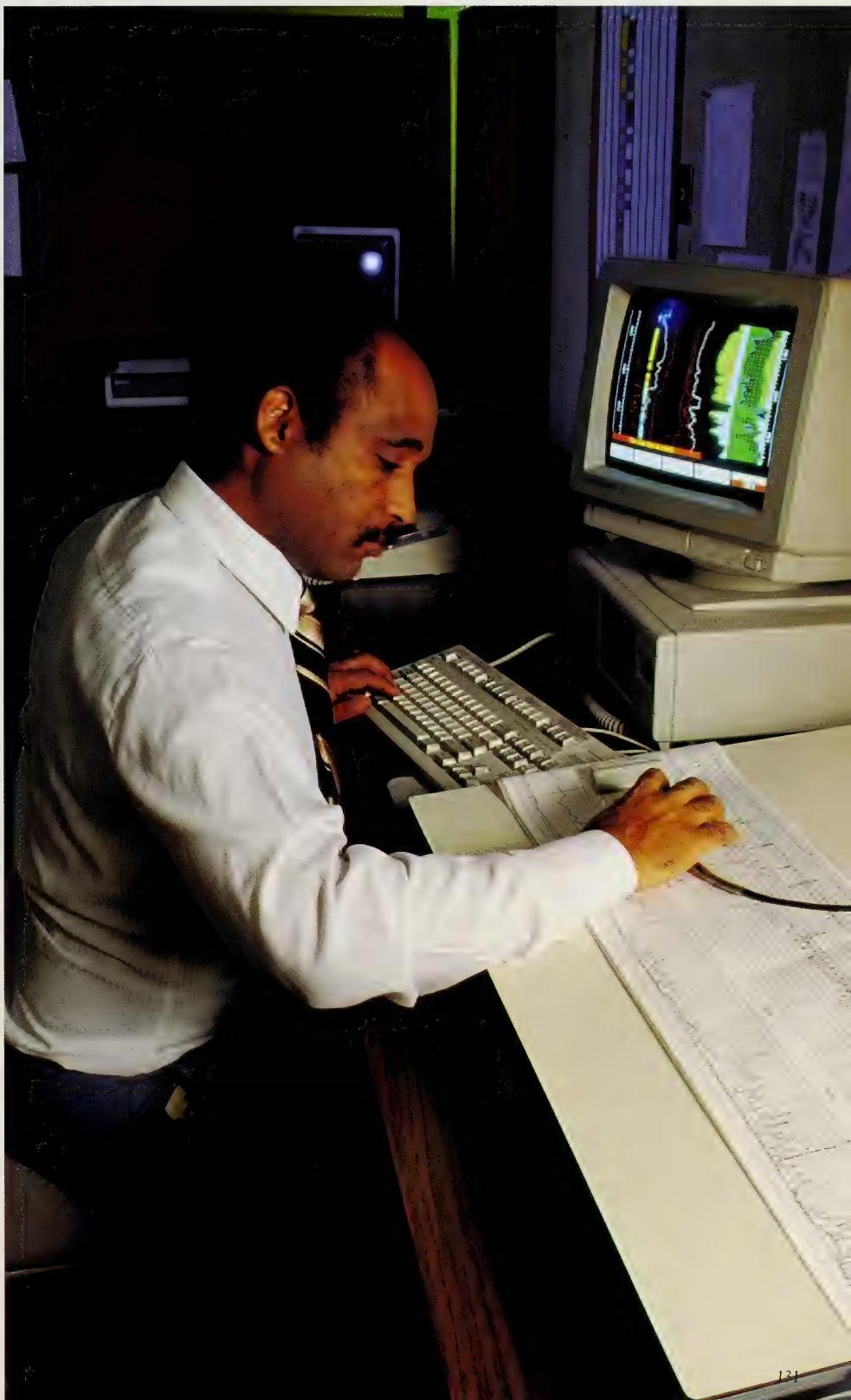
LEFT: Under the microscope, these cores are seen to be heterogeneous. A mathematical description of the microchannels through which oil must flow is recorded for use in interpretation of the mechanisms of flow of oil to a producing well. OPPOSITE PAGE: The many measurements and observations of each small layer of sediment in a core are recorded on a computer. These results are correlated to provide a three dimensional map of the deposit, its oil content, and its minerals.

During the intervening years, investigations at the centre have focused mainly on three areas: geology, thermal recovery and hydrocarbon upgrading. It is noteworthy that significant achievements have occurred in all three of these areas, and that the knowledge so gained has been transferred to industry. Let us examine these important research findings in some detail.

Geologists, for example, in the Alberta Geological Survey Group at the Alberta Research Council have learned valuable facts about the location, magnitude, and distribution of bitumen and heavy oil in the Athabasca, Peace River, Cold Lake, and Wabasca areas. This information is vital when choosing an in situ extraction method. In addition, bitumen-bearing carbonate rocks beneath the oil sands were studied. As more is learned about them, it likely will be found that they contain immense quantities of bitumen.

It was also through such geological studies that the site for the AOSTRA Underground Test Facility, located in the Athabasca oil sands, was chosen.

As very direct benefits from this resource documentation, industry and government have been provided with the geological facts necessary to accomplish optimal recovery of our vast oil sands and heavy oil resources.



A foam of soapy water and gas is used to push oil from all parts of the deposit to a producing well. This experiment tests the efficiency of production for the many soaps that are available and for different processes and injection strategies.



Concurrent with these geological accomplishments, the science of reservoir engineering has been advanced substantially during the past 15 years. Not only have studies at the Centre provided a better understanding of fluid flow in Alberta's reservoirs, but thermal extraction processes, that seem rather commonplace now, are directly derived from this work. To achieve this objective it was necessary to make observations of such reservoir properties as rock porosity, saturation of rocks by oil, bitumen behavior, and mineral transformations that take place when steam is injected into a deposit of bitumen. This involved a great deal of detailed research. What is more, many studies of extrac-

tion processes using steam or steam plus various additives were undertaken to coax bitumen out of formations and make it flow to the surface.

Typically, laboratory studies were carried out in large-scale, high-pressure vessels used to simulate reservoir conditions. Once scientists were convinced they had achieved something promising on this scale, they took their experiments into the oil sands and conducted larger-scale field trials. This sequence of events was repeated many times as various processes were assessed and either accepted or rejected. More often than not, a modification would be made, more laboratory studies would be done and additional field trials would follow. The Cold

Lake and Athabasca deposits proved particularly challenging and not willing to submit readily to extraction. In time, though, their secrets were exposed and processes capable of recovering more than 50 percent of the initial, in-place bitumen were developed and patented.

Thus, during the past 15 years, steam and steam-additive technology has been advanced from a relatively insignificant science to one in which the technical and economic viabilities of several processes have been proven and adopted by industry.

When steam is used to flood a reservoir to fluidize the heavy oil or bitumen so that they can flow to the surface, certain unstable phenomena can occur to make the process less efficient than desired. A term, called conformance, is used to express the fraction of the "pay zone" in a reservoir that is contacted by the displacing fluid. Therefore, experiments were conducted to improve the conformance and enhance reservoir performance. As a result, it was found that when substances called surfactants, were used along with steam and other additives, bitumen recovery rates increased by a factor of two or three over the use of steam alone. This process was patented in both Canada and the USA.

One of the problems solved by this research effort concerns a phenomenon called water-coning. This occurs when water from beneath an oil reservoir enters the production well during oil recovery. Thus, a well can produce a substantial amount of water along with oil. In field trials carried out by AOSTRA at one location, injection of non-condensable gases showed promising results. The research focused on learning about the mechanism of coning suppression by gas injection so that the process might be more widely applied elsewhere in Alberta. As a result, the conventional oil and gas industry, as well as producers of heavy oil and bitumen, were provided with a solution to a critically-important problem which they all have in common. This research program has made a significant contribution to support the Anti-Water-Coning Technology (AWACT) developed and commercialized by AOSTRA.

In a similar vein, "blocking agents" are sometimes needed in reservoirs to prevent production of unwanted fluids or to increase the yield of desired fluids. One method investigated, in simulated field trials, involved the use of ultramicro-bacteria, which are small enough to permeate a sand pack. When they are fed a suitable nutrient, they multiply and produce a polysaccharide



State-of-the-art methods permit wells to be drilled horizontally through a deposit. These wells may be a thousand metres long. However, with the oil and water that are produced, a small quantity of sand may also flow into the well. This experiment tests new methods to remove the sand that would otherwise settle and plug the well. *BELOW:* Canada's only pump-test rig permits close observation of working pumps under field conditions. Practical problems can be solved easily or improved designs can be tested.



slime. This slime can provide the necessary plugging and fluids suppression. The concept was originally developed at the University of Calgary, under the AOSTRA University Research Program. To advance its development under simulated field conditions, several experiments were conducted in large scale physical simulators. The results indicate that the process has applicability in suppressing water-coning.

One of the pivotal events in the evolution of reservoir science in Alberta was the

development of horizontal well technology. This unique method for recovering bitumen not readily accessible by surface or in situ methods is used at AOSTRA's Underground Test Facility. Before it could be used in the field, however, certain problems had to be overcome in the laboratory. One of those accomplishments was finding methods for preventing sand from entering and accumulating in the horizontal pipes. As it happens, it appears this sand-

control process may prove to be valuable for conventional vertical wells also.

In thermal, heavy oil operations, the produced bitumen must be pumped from the bottom of the production well to the surface. Although conventional pumps have been adapted and used for this purpose, their operation is affected by sand erosion, corrosion, and heat distortion. Therefore, a unique physical simulation system was constructed and is currently being used to im-

prove the design of pumps and to develop suitable pumping strategies. This facility is the only one of its kind in Canada, and the results it is producing have been well received by industry. Also, a unique bottomhole pressure sensor was conceived and developed. It is an improvement over conventional devices and is especially suitable for use in heavy oil wells. These are only two examples of the vast array of equipment designed and constructed to facilitate all aspects of this research.

During the past decade and a half, it has become apparent that Alberta is running out of the sweet, light crude oils which have been the mainstay of the provincial petroleum industry since 1947. While it has been believed for some time that the best option for replacing this oil is synthetic crude oil made from bitumen, only recently has a concerted effort been placed on finding efficient methods for converting bitumen to synthetic crude. Although the processes used at the Syncrude CAP project and the proposed OSLO and Husky Upgrader projects represent an improvement over those used at Suncor and Syncrude, there is a need to improve the conversion rate even further. This is the objective of a hydrocarbon upgrading program started in 1984 and funded jointly by AOSTRA and ARC. Thus far, laboratory studies have identified several promising upgrading processes.

Also of considerable value is the development of a process for preventing or minimizing the deposition of coke on the fire heater tubes, reactor walls, distillation towers, fluid transfer lines, and valves in a refinery when hydrocarbons undergo upgrading reactions.

This build-up of coke is undesirable because these deposits cause reduced heat transfer, and expensive equipment shutdowns are required to remove them.

Also, research has begun to identify reaction conditions under which upgrading can occur at lower temperature and pressure. This is important because these less severe conditions represent lower capital and operating costs.

Since the upgrading research began, High Pressure Facilities at ARC's Nisku Laboratories have been established. Currently, this pilot plant is the only one of its size in Western Canada and one of six in all of Canada.

As the capabilities of this centre of excellence have grown and expanded into new and exciting areas, there has been an increasing dependence on another science that has experienced a parallel growth: namely computer technology. Indeed, many of the achievements of this research program could not have happened with-

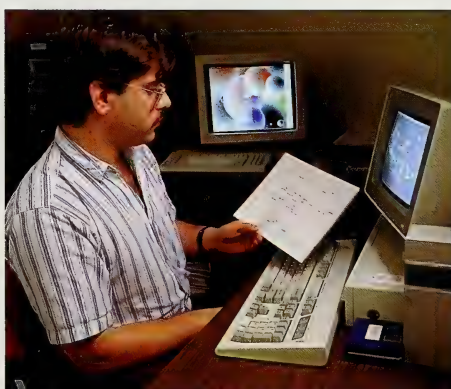
out the computing expertise that now exists. One example of this capability was the development of the Horizontal Wellbore Model for predicting the performance of the horizontal wells used at the Underground Test Facility. Also, virtually every other problem tackled in this broad research undertaking, ranging from studies of fluid flow in reservoirs to investigations of the behaviour of hydrocarbons inside a reactor, has benefited from numerical models developed especially for this program. This advanced computational capability represents a major accomplishment by itself.

BELOW: The pilot scale reactor shown in its protective steel shelter can refine bitumen at about one-third barrel per day. It is used to improve equipment and operation of novel hydrocracking processes.





ABOVE: Novel catalysts are specially formulated to increase the rate of desired chemical reactions. The result can be very large savings in the cost and operations of a refinery and an increased value of the products. LEFT: Applied mathematics is used to interpret the theories describing turbulent flow and many reactions that occur in the pilot-scale reactor. This important step in the interpretation provides a description of how the novel process being tested will behave in a large commercial plant.



LEFT: Computers are used to monitor and record the readings from the many instruments that measure the reacting fluids at their high temperatures and pressures.

IN 1964, DR. G.W. GOVIER, CHAIRMAN OF THE OIL AND GAS CONSERVATION BOARD, DR. E.J. WIGGINS, DIRECTOR OF THE ALBERTA RESEARCH COUNCIL AND DR. R.M. HARDY, DEAN OF ENGINEERING, UNIVERSITY OF ALBERTA, PREPARED THE INITIAL PROPOSAL FOR THE FORMATION OF THE PETROLEUM RECOVERY INSTITUTE (PRI) FOR PRELIMINARY DISCUSSION WITH GOVERNMENT AND INDUSTRY.

A review of the oil industry had indicated that very little research relating to oil recovery was being conducted in Canada and that Canada was relying almost entirely on results of work being done outside the country. At the time it was estimated that average recoveries would be approximately 22% of the oil-in-place by primary recovery methods and that further research and

development could increase this recovery to nearly 34%. Therefore, exciting opportunities existed for further improvement in recovery through research. Here, it should be noted that an improvement of 1% in recovery would represent 8.2 million cubic meters (517 million barrels) of additional oil produced, based upon the in-place initial conventional crude oil of 82 billion cubic meters (51.7 billion barrels), as of December 31, 1988. This would be equivalent to finding an oil field containing three times this amount, i.e. well over a billion barrels, tantamount to a major discovery.

It was also pointed out in the PRI proposal that the presence of an active research institute in Canada would serve to attract students to engineering careers in areas beneficial to the petroleum industry. The response to the proposal for such a research institute from the petroleum

industry and the Government of Alberta was positive and the Petroleum Recovery Institute was established under the Alberta Companies Act as an independent non-profit organization on December 2, 1966. With joint funding provided by the Alberta Government and the oil industry, the Institute started operations at the University of Calgary in 1966, with the general mandate to conduct fundamental research directed toward increasing the recovery of oil from underground reservoirs.

Currently, PRI has a Board of Directors composed of Industry, University and Government representatives. The Board sets down the operating policy within the framework of the Institutes' Articles of Association. The Executive Director has the overall responsibility for the management of the Institute, heading up a staff of 34 people. The offices and eight laboratories of the Institute occupy at present two floors of the north wing of the Energy Resources Research Building in the University Research Park. Departments of the University of Calgary which have strong links to PRI

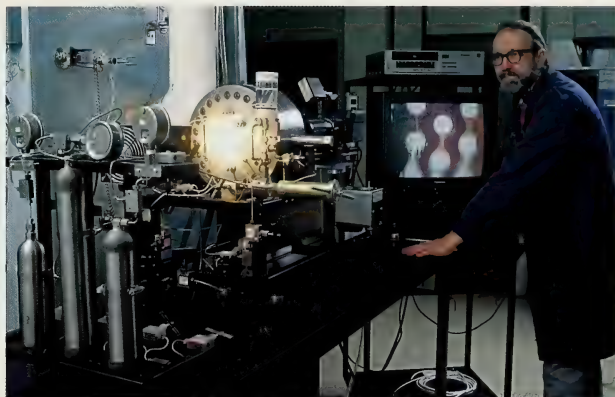
Visual analysis of rock surface properties, such as interfacial tension, adhesion, and contact angle, are made using the contact angle apparatus shown being operated by staff technologist Marcel Girard.





are Academic Computing Services, Communications Media, and the Libraries. Liaison with the university library system is maintained through the I.N. McKinnon Memorial Library which serves all sections of the Energy Resources Research Building.

The Board has several standing committees with the Technical Advisory Committee of particular importance. This Committee is chaired by a Member of the Board of Directors and has representatives from the University of Calgary, the Alberta Research Council, the Alberta Energy Resources Conservation Board, Federal

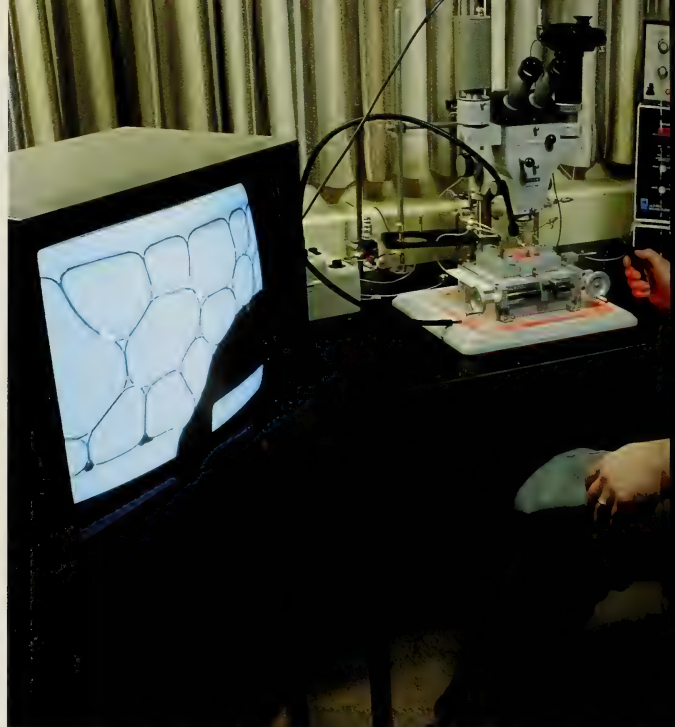


Energy, Mines and Resources, and the petroleum industry. Committee Members from the industry are selected partly from local companies in Calgary and partly from major petroleum research centres in the USA. As a result of this broad representation, the Committee can provide expert technical guidance to the Institute from both the public and private sectors, relating to the oil industry.

The Technical Advisory Committee serves to assist the Institute in developing its programs. More specifically, the Committee considers those areas of research most appropriate to the Institute, on the basis of its knowledge of the research currently being carried out by industry, and in general, advises the Board of Directors on all aspects of the research program.

LEFT: Senior staff technologist Douglas Fisher is analyzing the results of a high pressure gas flooding experiment being conducted in a micro model. ABOVE: Staff technologist Joseph Najman is shown adjusting a video monitor displaying the highly magnified results of a micro model test. Visual analysis of asphaltene precipitation can be observed when solvents contact heavy oil in the micro model.

A foam propagation test to demonstrate the ability of foam to move through reservoir rock is being conducted in a long core. The test is being monitored by senior technologist Vladimir Masata.



In 1984 the Board conducted a thorough review of Institute research priorities. On the basis of this study, research programs focussed on the following four areas of enhanced oil recovery research:

- heavy oil recovery by steam flooding, CO₂ and other additives;
- gas flooding with miscible and immiscible fluids;
- improvement of reservoir sweep efficiency; and
- chemical flooding.

In addition, four subcommittees were organized to review progress and provide guidance to PRI staff members between the annual meetings of the Technical Advisory Committee. Presently there are 24 member companies and one associate member in PRI. Fifty percent of PRI funding comes from membership fees, and fifty percent from an annual grant in support of research from AOSTRA. Some additional revenue is received through specific contract work for

industry, and for government agencies. The annual budget of the Institute is approximately \$2,000,000 per year for the Core Research Program, described below.

Basic research is carried out under the Core Research Program which was established in 1966 and continues to this date. The Program is supported on an equal basis by the Industry members and the Alberta Government, through AOSTRA. It is critically reviewed annually so as to meet the overall requirements of the member companies and the participating agencies. Emphasis is on projects of general interest to the funding members but not specific to their individual needs. Contract research, on the other hand, is conducted by the Institute to meet the specific requirements of member companies and the oil industry in general. Contract research income has grown over the years so as now to represent a significant por-

tion of PRI income. The Core Research Program's plan for the fiscal year 1989-90 is divided into general enhanced recovery areas as shown.

CORE RESEARCH PROJECTS

A. Gas Flooding Projects

1. Displacement Efficiency in Miscible Gas Flooding
2. Rock Fluid Interactions in Hydrocarbon Flooding
3. Effect of Surface Adhesion on Oil Recovery

B. Surveys Improvement Projects

1. Foam Performance in Porous Media
2. Surface Adsorption
3. Oil-Foam Interaction
4. Blocking and Diverting

C. Heavy Oil Projects

1. Relative Permeability Characteristics of Heavy Oil Systems
2. Fines Migration Problems

3. Rheology of Heavy Oil and Water-in-Heavy Oil Emulsions
4. CO₂/Heavy Oil Phase Behaviour

D. Chemical Flooding Project

1. Alkaline Polymer Synergism
2. Surfactant-Enhanced Alkaline Flooding
3. Co-Surfactant/Alkaline - Polymer Systems

E. Geology Projects

1. The Effect of Firing on Brea Sandstone
2. Solidified Residual Thin Sections
3. Geologic Micro-modeling

Research findings are reported to the Institute's members and to the oil and gas industry in general by means of reports, presentations at seminars and conferences and by publication of papers in a variety of technical journals.



LEFT: A video monitor displays the interaction between foam and oil in a micro model test of foam displacing oil. Staff research chemist Laurier Schramm is shown observing the test.

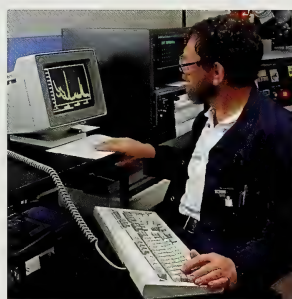
sis method for improvement of in situ recovery of bitumen, as developed by Drs. Hyne and Clark at the University of Calgary, again through the University Access Program. These laboratory technologies need larger-scale testing before going to the field, which PRI is equipped to do but the University laboratories are not. There is considerable industry interest in these methods since many companies participate in the University Access Program.

In addition to the research reports coming from the Core Program, PRI has supplied AOSTRA with advice and guidance, as well as critical evaluations of data generated from AOSTRA's enhanced oil recovery field pilots. This has allowed AOSTRA to accelerate technology development in its non-thermal field pilots, where PRI has considerable technical expertise. In addition, AOSTRA has utilized the laboratory facilities and programs of PRI to carry forward to the intermediate development stage, very promising enhanced oil recovery basic technologies, generated through AOSTRA support. Examples of this type of development stage would be the field core tests of bacterial blocking agents, for anti-water-coning, developed by Dr. Costerton of the University of Calgary, through the AOSTRA University Access Program, and the core testing of the in situ iron aquathermoly-

The flexibility to rapidly do further testing and development of such types of promising technology will ensure the most rapid transfer of new technology from discovery in the laboratory to the field. As with all AOSTRA programs, the interest and participation of industry is encouraged at all stages.

After 23 years of operation, PRI continues to serve the needs of industry and has established a world-wide repu-

tation for excellence in enhanced oil recovery research. The vision of Drs. Govier, Wiggins and Hardy has been fully realized through the development of this world-class research facility that has jointly and uniquely been sponsored through the cooperative efforts of the oil industry and the Government of Alberta.



ABOVE: Senior staff technologist Neil De Bree is using an x-ray diffractometer to analyze the mineral components of rock samples. RIGHT: Senior technologist Rosemary French is operating a surface area analyzer which measures surface area of porous rock through nitrogen adsorption.



ABOVE: The operation of a scanning electron microscope is demonstrated by research geologist Peter Churcher. The equipment is used to study pore geometry and to identify rock constituents.

EARLY IN ITS OPERATIONS AOSTRA REALIZED THAT IF MAJOR EXPLOITATION OF ALBERTA'S IMMENSE OIL SANDS RESOURCES WAS TO TAKE PLACE, LARGE NUMBERS OF SPECIALLY EDUCATED PEOPLE WOULD BE REQUIRED.

To this end, a number of specific programs were established with, as their principal goal, a preparation for a career in the broad field of oil sands recovery and processing.

UNIVERSITY SUMMER STUDENT PROGRAM

To provide summer employment for university students, give them experience in oil sands research, and encourage them to proceed after graduation to advanced degrees in oil sands research, AOSTRA started in 1983 to employ second and third year students during the summer months when they were not in classes.

CO-OP AND SUMMER STUDENT PROGRAM

To increase the effectiveness of AOSTRA projects, provide employment for university students interested in a long term career in the oil sands and heavy oil industry, AOSTRA began in 1979 to employ both summer and co-op students either to work in AOSTRA's offices or on many of AOSTRA's field projects. Starting with four students in 1979, the program grew to 14 students in 1988. Many of these students have continued on to careers in the petroleum industry. In total, 81 students were employed under this program.

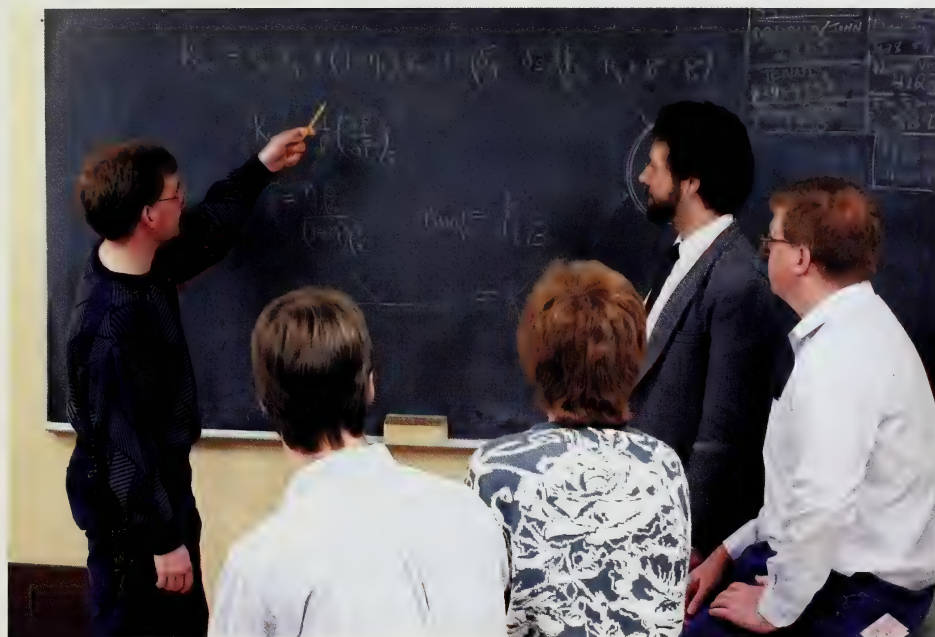


ABOVE: Roger Butler and some of his students vigorously discuss Roger's latest theory describing mechanisms by which steam causes heavy oil to flow to a horizontal well. OPPOSITE PAGE: Tim Spanos (with beard) and his students hone their skills in research by applying advanced mathematical physics to problems of sound transmission through oil sands.

These students were paid by AOSTRA but normally worked on one of AOSTRA's many university research projects. With the exception of 1987, this program has placed 20 students each year for a total of 120 students. Many of these students have become so enthusiastic about oil sands research that they have gone on to obtain Master's and Ph.D.'s in the field and are now making a major contribution to unlocking the secrets of the oil sands.

THE MASTERS DEGREE IN OIL SANDS ENGINEERING

To encourage graduates of other faculties to concentrate on the field of oil sands technology and become involved with the industry, AOSTRA, in cooperation with the Faculty of Engineering at the University of Alberta, sponsored a Masters of Oil Sands Engineering Program. Under this program, students completed 10 post-graduate courses, together with a study project and spent one year working in the industry. Twenty-four students from a wide variety of backgrounds took this program during the four years that it was offered. Many of these are now employed in the petroleum industry.



NEW GRADUATE ASSISTANCE PROGRAM

In 1986, AOSTRA in a further effort to attract new graduate engineers and geologists into the industry, initiated the New Graduate Assistance Program. Under this Program new graduates were offered a one year fellowship, renewable for a second year, to work with a professional geologist, geophysicist or engineer on an oil sands, heavy oil or enhanced oil recovery project. In addition to obtaining valuable experience and furthering the technology, new graduates were able to obtain the experience required for professional registration. Since 1986, twelve professionals have received such awards and many of these have moved on to careers in the industry.

SCHOLARSHIPS AND FELLOWSHIPS

To encourage graduate students and postdoctoral fellows to do research in petroleum recovery and processing at Alberta universities, AOSTRA in 1976, in cooperation with the Alberta universities, instituted a program of scholarships and fellowships. These awards were open and made on the basis of academic excellence with the only restriction being that the work be conducted at an Alberta university and that the research be in the broad area of petroleum recovery and processing. Since 1976, 106 scholarships and 25 postdoctoral fellowships have been awarded under this program. In 1988 the program was ex-

panded to give supplemental awards to holders of major scholarships, such as NSERC scholarships, thus encouraging some of the very best students to come into the field of our mandate.

INDUSTRIAL POSTDOCTORAL FELLOWSHIPS

The success of the postdoctoral fellowship program for university research suggested to AOSTRA that this same concept may be employed to encourage research and the placement of new graduates in the petroleum industry. In this program, AOSTRA awarded a postdoctoral fellowship similar to that offered at universities but the research was conducted at an Alberta industrial research laboratory. Usually the

industry matched the funds provided by AOSTRA. Four awards have been made to date in this program.

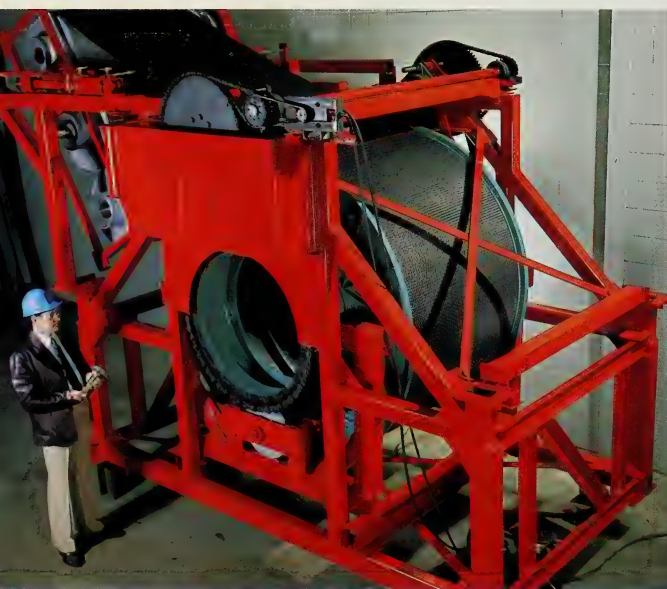
NAIT/SAIT STUDENT PROGRAM

To expand the technical staff for AOSTRA's many projects both in the laboratory, and in the field, provide summer employment for students from post-secondary technical schools, such as NAIT and SAIT, in order to give them experience in the petroleum industry and encourage them to become part of it after graduation, AOSTRA in 1988 instituted a new program. While the students were hired directly and paid by AOSTRA, they were selected by AOSTRA's industrial and institutional partners and worked directly on their projects for the summer months. Sixteen students were thus employed in 1988 and 20 in 1989.

CONCLUSION

From the above it can be seen that AOSTRA has been very active in providing the means and the incentives for bright, young people to develop technical careers in those fields which are needed to exploit fully the vast potential of our oil sands and heavy oil resources.

INDIVIDUAL ENTREPRENEURS HAVE ALWAYS EXPERIENCED MANY DIFFICULTIES IN BRINGING THEIR INVENTIONS TO THE MARKETPLACE. THIS IS PARTICULARLY TRUE IF THE INVENTION IS STILL IN CONCEPTUAL FORM. AOSTRA RECOGNIZED THIS REALITY EARLY AND AS A RESULT IMPLEMENTED IN 1983 THE INVENTORS GRANT ASSISTANCE PROGRAM (IGAP).



Inventor Jan Kruyer beside his prototype "Oleophilic Sieve" that can separate bitumen from sludge being fed at a rate of 1000 tonnes per day.

The main objective of this program is to help entrepreneurs develop their inventions sufficiently beyond the "rough concept" stage so that patent protection may be obtained and meaningful negotiations for further development or commercialization may be set in motion. The assistance is in the form of an outright grant up to a maximum of \$50,000.

Now in order to obtain a grant, the inventor must apply to AOSTRA. A panel of experts reviews the application and one or more of these experts interviews the applicant. If possible, this interview is done at the applicant's place of business. On the panel's recommendation, AOSTRA may sign a contract with the inventor. With the contract in hand, the inventor can develop his invention at least to the stage where conventional financial support is available. IGAP funding is provided as the work progresses.

AOSTRA owns the reports that are received but does not earn any use rights to the inventions. The only requirement on the part of the inventor is a commitment to use the funds appropriately to develop the invention and to supply accounting and technical reports to AOSTRA.

This continues to be a very popular program. Since 1983, \$1,221,404 have been committed to 37 contracts with inventors.

A majority, but by no means all of the inventions are by oil-field specialists who have conceived of a better means of performing some task. In the following paragraphs, some of these devices are described. The inventors deserve a great deal of credit for their courage and perseverance.

On mixing mined oil sands with water, inventor Jan Kruyer observed that not all the droplets of oil rise to the surface. This is particularly true if significant amounts of clay are present. However, most of this oil will stick to certain oleophilic (i.e. oil-loving) materials such as plastic or specially treated steel. Accordingly, a simple device was constructed to pass a wide belt of oleophilic material through the slurry then between two rollers that squeeze the oil off the belt. This belt forms a loop and therefore oil may be extracted continuously.

Kruger succeeded in obtaining patent protection for his device. However, while negotiating for large-scale testing of his device he recognized that additional patenting was needed to protect some improvements that he had made in 1980 to 1982. One of these improvements was to construct the belt of steel wire woven to form a sieve. On receiving an IGAP grant in 1983, he filed four applications for patent. These provided the needed protection which permitted successful negotiations for large-scale testing of his device at one of the commercial oil sands plants near Fort McMurray. These tests are now complete and the results indicate that a promising new technology has been created.

While working on and near drilling rigs, inventor Bruno Walter reasoned that if the drill bit could be cleaned more efficiently of chips and small particles of rock, then energy would not be wasted in simply regrinding these chips. The result would be a markedly improved rate of penetration of the drill. To accomplish this, Walter designed the "Mud Hammer," that could be fitted into the long string of drilling pipe, just above the drill bit.



Inventor Bruno Walter with Raymond Lemaire of Intech Drilling assembling "Mud Hammer" for shipment to a drilling rig.

On receiving an IGAP grant in 1984, Walter constructed and tested a prototype of his Mud Hammer. The Hammer worked almost as predicted. The drill string vibrated and the mud was squirted in strong pulses between the teeth of the drill bit. Clean rapid penetration of the drill bit was observed but some improvements were needed to reduce wear of the vibrating components and plugging within the Hammer.

On receiving a second but smaller IGAP grant in 1986, Walter made the needed improvements. Field tests were successful. Patent protection followed. Now with the experience of 22 bit runs all showing about a 20% increased rate of

penetration in hard rock and shale, Walter has good field evidence and strong operator enthusiasm for his Mud Hammer. An Alberta company is successfully leasing the Mud Hammer to many drillers in Canada.

BELOW: Inventor Ron Woronowicz describes to AOSTRA's Mel Farries the progress in his business plan for the manufacture and sale of his novel ball valve. The valves shown are made of stainless steel to resist corrosion in sour gas and hydrogen sulphide. The sealing system is self-cleaning and self-adjusting.



In principle, the conventional oil pump differs little from the old style pump that one may still encounter on some farmsteads. As the handle is moved, the sucker rod is raised and lowered in the well and with it the plunger of the pump. Such a pump works efficiently and without problems provided that the water or the oil does not contain too much sand.

Many of the heavy oil wells in eastern Alberta near Lloydminster and Wainwright produce a great deal of sand and water, particularly if the well is a new one. The Moineau pump is particularly well adapted to pumping such troublesome fluid mixtures. It is not basically a very efficient pump but it is certainly effective.

The operation of the Moineau pump differs markedly from a conventional one. Instead of lifting and lowering the sucker rod, the sucker rod is rotated. The pump at the bottom consists of a long screw or helix that is rotated slowly by the sucker rod within a helical pipe of slightly greater pitch. The helical pipe is usually lined with tough rubber that will withstand abrasion by the sandy oil being pumped.

While working with these pumps, Robert Mills observed that the thin sucker rod would "wind up" then unwind suddenly as particles of sand were pumped along with the oil. This surging and winding up accelerated wear of the pump. What Mills invented was an improved method of rotating the pump.

On receiving an IGAP grant in 1984, Mills constructed and tested a prototype of his newly designed pump. The successful principles of the Moineau pump were retained but the sucker rod was removed and instead the tubing was attached to the helix. The helical pipe in turn was fixed to the casing. This design was tested and found to work very well indeed. However, there was still a good deal of development work to be done.

After only a few months of operation, the first unit failed. Careful examination showed that particles of sand had fouled a bearing. Repair of the pump proved to be simple and required about one third the rig time needed for a conventional pump. Most encouraging was the observation that the critical components of the Moineau pump were "as new." The design principle had been proven.

Few inventions work on the first, second or even the third testing. More problems of materials selection were discovered and solved. The oil companies that installed the pump in their wells should also be credited with courage and farsightedness. Out of this long process, inventor Mills created an excellent pump.

At present, the Mills pump is installed in a troublesome well, one that had been used in a now-abandoned in situ combustion operation. The well, too, was about to be abandoned since the oil was too viscous and too sandy to be produced by any other means. The pump continues to work after many months of operation. The sandy oil that is produced has the consistency of axle grease, presenting a new challenge for some inventor.

Directly produced oil cannot simply be sent to the pipeline and on to market. The oil must be cleaned of sand and water first. The produced oil is pumped from the well to a large tank where the sand and water tend to settle. Further cleaning is still required, but let us focus our attention here on what happens to the oily wet sand that from time to time must be removed from the settling tank.



One of the dirtiest tasks most disliked by operators is that of "mucking out" or cleaning this large tank. When the tank becomes too full of sand, the oil is pumped away and large manholes are opened near the bottom of the tank. Inventor Wayne King had a great deal of experience with this unpleasant operation and being an inventor he designed a clean solution which he called the Grit Hog.

On receiving an IGAP grant in 1987, King developed a working prototype of the Grit Hog. It worked extremely well and continues to do so. The photograph tells more than words. The device is mounted on the front of a tractor and consists of a hydraulically-man-



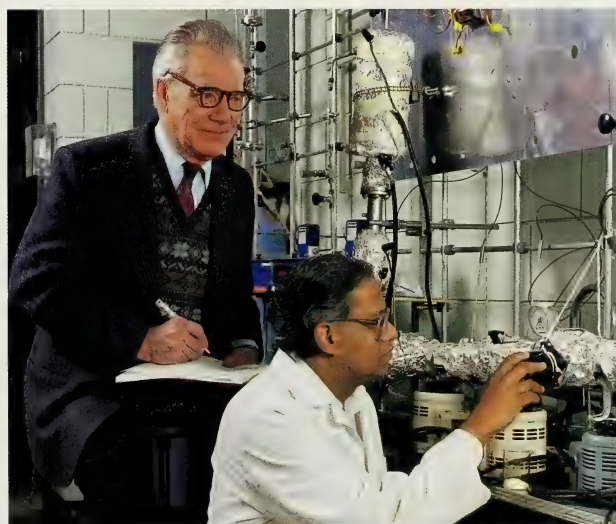
LEFT: This picture shows The Grithog just assembled and ready to clean out more than 500 settling tanks. BELOW: Inventor Eric Tollefson testing his novel device for removing hydrogen sulphide from natural gas.

euvered auger that can reach through the manhole and pull out the oily muck lying at the bottom of the tank. The muck lands in a large box from which it handled easily. Inventor King is doing very well with this successful invention and has sought patent protection.

Most gas wells produce, along with the natural gas, a small amount of hydrogen sulfide. This is not a serious problem if the well is connected by pipeline to a convenient treating plant for removing the hydrogen sulfide. However, if the well is isolated and if the gas is needed directly for fuel, then there is an environmental problem. Indeed, it is a common one. Many of Alberta's oil producing wells are in remote areas and produce along with the oil just enough gas to fuel the operation.

Inventor Eric Tollefson observed that sand coated finely with certain metals will efficiently adsorb appreciable amounts of oxygen from the air and if subsequently immersed in natural gas, will oxidize the hydrogen sulfide therein to produce sulfur and water. The reaction is very efficient. Recognizing the problem described above, Tollefson designed a unit to be attached to a producing well.

On receiving an IGAP grant in 1989, Tollefson constructed a prototype of his oxidizer and tested it. The tests were successful. An economic evaluation of the device shows it to be commercially promising. Now, with patenting completed, Tollefson can negotiate securely for commercial development of his novel Alberta device.



The foregoing examples illustrate how the IGAP program has assisted many Alberta inventors to move their inventions along the difficult road to commercial reality. These new business ventures expand the base of Alberta technology, and create many stimulating employment opportunities for our people.

THE AOSTRA PHILOSOPHY ON TECHNOLOGY OWNERSHIP AND TECHNOLOGY TRANSFER SETS AOSTRA APART FROM OTHER TRADITIONAL GOVERNMENT FUNDING AGENCIES. THE AOSTRA PHILOSOPHY IS THE CORNERSTONE WHICH HAS PROVIDED "AN AMAZING NARRATIVE OF AN EFFECTIVE PUBLIC SECTOR/PRIVATE SECTOR PARTNERSHIP THAT IS SIMPLY UNPARALLELED ON THIS CONTINENT, EXCEPT IN THE MONUMENTAL ACHIEVEMENTS OF THE SPACE EXPLORATION PROGRAM" (OILWEEK EDITORIAL BY FRANK DABBS, JULY 3, 1989).

The traditional method of operations for a government agency funding research work is to require that all data from the research be public knowledge. AOSTRA chose a different method and the combined AOSTRA and industry efforts over the past 12 years have developed a billion dollar pool of technology which can be made available under suitable licensing arrangements.

The basic conditions attached to AOSTRA financial participation for technology development is that the results of the technology development are confidential and that AOSTRA owns the technology developed during the course of the project. This method of operation was developed after wide consultation with industry, the universities, and Alberta Government officials during the formative years of AOSTRA operations.

Ownership of the technology is necessary to enable AOSTRA to make the technology developed with public funds accessible to any legiti-



ABOVE: At the field site of an AWACT test, Brad Anderson (left) and Mike Chmilar monitor the progress of the well treatment designed to increase oil production while reducing the water to oil ratio of the produced fluids. RIGHT: Ken Kisman, AOSTRA principal reservoir engineer (seated), discusses results of the latest AWACT (anti-water-coning technology) field test with Boyd Russell (left) and Randy Freeborn of Alberta Energy Company.



mate user on suitable terms. The technology is made available at fair market value rather than free of charge. Thus, the technology is freely available but not available free.

This policy was created so that companies could propose the most promising technologies to AOSTRA for further development without concern that the results would become immediately available, free of charge, to their competitors. It would be clearly unfair to companies who shared in the costs and technical risk of a project if their competitors could sit idly by and wait for the results to be openly published.

In practice, AOSTRA, as owner of the technology, acts as the exclusive licensing agent in Canada on behalf of the project participants. AOSTRA and the project participants negotiate a fair market value for the technology and share in any license revenue in proportion to participation in the project. If the participants and AOSTRA cannot agree on a fair market value, then the value is set by arbitration. This vital point means that all technology developed with AOSTRA funding is available under fair market terms and conditions.

It should be pointed out that where mutually agreeable, papers are published which describe the results of AOSTRA-funded research work. AOSTRA projects have generated hundreds of publications over the 15 years of AOSTRA operation. AOSTRA projects in total have generated more oil sand and heavy oil related publications than any other organization in Canada. AOSTRA operations are confidential but not secret.

AOSTRA has also established the AOSTRA Journal of Research which is a prestigious technical journal, publishing regularly refereed papers on major oil sands, heavy oil, and enhanced recovery technology.

AOSTRA has, in addition, a number of technology transfer and licensing programs in place. The transfer programs and rationale for these programs are described below.

A. TECHNOLOGY PACKAGES PROGRAM

Within AOSTRA, "Technology Packages" means completed studies or reports resulting from smaller projects, as well as feasibility studies, together with distinct investigations and reports which are small stand-alone parts of a larger project. These packages are available on a fixed cost basis. AOSTRA periodically generates a listing of these

technology packages and holds a sale where the packages may be reviewed and selected, for purchase by interested parties.

B. CONSULTIVE PARTICIPANTS PROGRAM

In order to speed the transfer of technology and thus the rate of its development in Alberta, AOSTRA recognized that it is inefficient to wait until a multi-year project was completed before the technology was offered for license and access. Consequently, AOSTRA developed a program whereby interested parties could have ongoing access to a project, submit suggestions as the project progressed, and finally earn technology use rights to the results. This program is termed "consultive participant access." Simply put, the consultive participant is closely equivalent to a silent partner in a business venture. The consultive participant has ongoing access to the project and earns the right to use the technology that emerges.

The consultive participant fees are set by AOSTRA in cooperation with project participants and in those cases to date, the consultive participant fees have been in the range of 6 to 10% of the project costs.



In the AOSTRA Calgary office, engineers Denise Rechel and Mike Chmilar manipulate computerized data from AOSTRA-sponsored field pilots, while technical representative Don Wright, and Brad Anderson, technology transfer and commercialization officer, discuss the results in the background.



C. AOSTRA UNIVERSITY ACCESS PROGRAM

AOSTRA selects university research projects and fully funds the projects.

University projects tend to be at the frontiers of knowledge and technology and there are, therefore, definite possibilities for significant scientific breakthroughs. In order to accelerate the transfer of such technology to industry, the University Access Program was developed by AOSTRA. The interested party pays a fee for ongoing access to the data and use rights to the technology. AOSTRA and the Industry Access Program participants jointly review the proposals for further research support received from University researchers and make recommendations for further funding.

D. AOSTRA ACCESS PROGRAM FOR RESEARCH AT THE ALBERTA RESEARCH COUNCIL

The AOSTRA Access Program for ARC research operates in a similar manner to the University Access Pro-

gram, and provides companies ongoing access to the AOSTRA-funded work at the Alberta Research Council for a modest fee.

E. AOSTRA LICENSE PROGRAM FOR PETROLEUM RECOVERY INSTITUTE

AOSTRA and industry jointly fund research into the development of enhanced oil recovery technology at the Petroleum Recovery Institute (PRI) in Calgary. The PRI is the major laboratory technol-

ogy development organization for enhanced oil recovery technology in Canada. AOSTRA is the owner and exclusive licensing agent for this technology developed at PRI. The fees for licensing of the technology are jointly set by AOSTRA and the sponsoring companies. Through AOSTRA the enhanced oil recovery technology emerging from PRI is available for licensing on a world-wide basis.

F. AOSTRA DATA BASE SYSTEM

As a support mechanism to collect, store, and transfer AOSTRA data from pilot operations, the AOSTRA data base system was set up. Data comes directly to AOSTRA from the field projects. The data can be accessed in a computerized form by project participants and consultive participants. The data is stored and manipulated on AOSTRA's in-house computer

facilities. The system is also used by the project operators for project data manipulations and preparation of reports to regulatory agencies.

G. PUBLISHED INFORMATION

The AOSTRA Library and Information Services have been set up to provide a comprehensive service to industry for access to and retrieval of published information. The service has the most comprehensive set of published papers in the oil sands and heavy oil areas available in Canada. The service is available through both the Calgary and Edmonton offices of AOSTRA.

H. AOSTRA INTERGOVERNMENT TECHNOLOGY LICENSING

Oil sands are widely distributed throughout the world. Governments of foreign countries often prefer to approach AOSTRA, in the first instance, to begin a development program for their particular oil sands deposits. Upon request, AOSTRA has cooperated with countries not possessing adequate technology infrastructures by assisting them to evaluate oil sands reserves, to

train personnel, to arrange access to technology, and to recommend suitable consultants and contractors, available in Alberta, to work with them in their oil sands development.

When AOSTRA was formed it was recognized that it would be impractical to attempt to develop all technology exclusively in Alberta. AOSTRA's international technology license program was thus structured so that technology developed by AOSTRA is available for license and transfer to industry and to other countries on a world-wide basis. Also, to ensure that the latest and most promising technology is available to be applied to the development of Alberta resources, AOSTRA's program is designed to search the world for promising technology and transfer that technology to Alberta for Alberta resources development. The AOSTRA international technology license program is thus a two-way street.

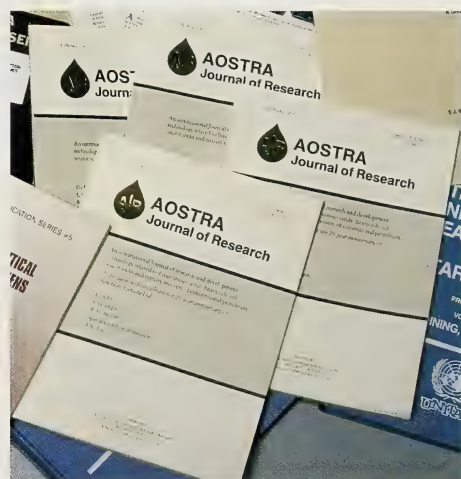
With countries which have active oil sands or heavy oil development programs, AOSTRA has arranged technology cross license arrangements be-

tween the industries in Alberta and the particular country. Also, joint experimental programs have been initiated which continue to provide new technology.

As a result of AOSTRA's technology licensing activities, almost every company involved in the oil sands, heavy oil, or enhanced oil recovery in Alberta has entered into a technology transfer agreement with AOSTRA, as well as a broad spectrum of offshore companies, together with federal and foreign governments. The cumulative cash revenue to AOSTRA from technology licensing activities is of the same order of magnitude as AOSTRA's share of oil pro-

duction revenues from all of AOSTRA's field pilots combined. The cash revenue from technology licensing has been enough to offset, in large part, the total staff, administrative, and office costs of AOSTRA.

Technology and access to that technology at fair market value is of vital importance to the development of oil sands and heavy oil resources in the future, in both Alberta and around the world. AOSTRA technology is available under the terms described above and AOSTRA is prepared to respond to all technological needs for resource development within our mandate.



THE TECHNOLOGICAL ADVANCES MADE BY AOSTRA AND ITS MANY ASSOCIATES, OVER THE PAST FIFTEEN YEARS, WOULD HAVE BEEN NEXT TO IMPOSSIBLE WITHOUT FACILITIES FOR THE RAPID DISSEMINATION OF THE LATEST TECHNICAL INFORMATION ON ALL MATTERS RELATING TO THE RECOVERY AND PROCESSING OF BITUMEN AND HEAVY OILS, AND TO ENHANCED RECOVERY TECHNIQUES AND STRATEGIES FOR CONVENTIONAL OIL RESERVOIRS. INDEED THIS VITAL NEED WAS CLEARLY RECOGNIZED IN AOSTRA'S ORIGINAL MANDATE AS DEFINED IN 1974.



Dr. Doug Schmitt, University of Alberta, has just completed his progress report on seismic tomography and geophysical properties of oil sands. As part of the service provided by ALIS, Dagmar Losert is searching for related data on the AOSTRA University Research Program database.

It was to meet this fundamental requirement that the AOSTRA Library and Information Services (ALIS) was established in 1975. The facility was first known as the Alberta Oil Sands Information Centre; the ALIS acronym was adopted later to recognize the expanded services provided under full computerization.

Initially the most pressing need was for a one-step information centre, covering the full spectrum of oil sands technology from geology to analytical methods and computer modelling. This proved to be a very complex undertaking since oil sands technology overlaps many established research disciplines, and there was a lack of multidisciplinary research journals in which to report new technological developments. As a result the gathering of the documents in which the required information was stored was often a very time-consuming operation. But the need was extremely urgent to provide engineers and researchers with the knowledge base on which to build new advancements.

Ultimately hard copies of all the relevant documents were acquired. With the invaluable assistance of experienced information officers covering the various specialized fields, such as geology and petroleum engineering, the information was keyworded and abstracted, and set up for information retrieval by computer. This was the beginning of the Alberta Oil Sands Index.

As research and development in oil sands technology proliferated, further information became necessary on "who was doing what" in this rapidly expanding field. This led to the creation of the Project and Personnel File, which was printed and computer-keyed in 1979.

With AOSTRA's expanded mandate to include enhanced oil recovery, and a greater emphasis on heavy oil technology, ALIS met the challenge by developing the Heavy Oil/Enhanced Recovery Index which began operations in 1981.

As the petroleum industry matured, in the areas of AOSTRA's mandate, the need for the Project and Personnel File diminished. It was phased out in 1983.



Dr. Joseph Liu, Syncrude Canada Ltd., is conducting research on tailings treatment. Gene Lau searches online for relevant information on the Alberta Oil Sands Index database. Once Dr. Liu has decided exactly what documents he requires, they are copied and given to him before he leaves.

The vast reservoir of technical information accumulated by ALIS in computer-accessible form represented a unique resource in the world, and it was not long before international clients began taking advantage of this special facility. Requests began pouring in from technical people in Venezuela, Europe, the USA, Japan, China, and Madagascar.

The ALIS staff is justifiably proud of its ability to answer information requests within 24 hours, and this remains the standard by which the service operates.

As the pioneering information retrieval centre in this important field of knowledge, ALIS has willingly assisted other information centres to set up similar facilities. Here particular mention should be made of the UNITAR/UNDP Information Centre on Heavy Crude and Tar Sands in New York.

Over the years, AOSTRA has also accumulated an enormous amount of confidential data in its joint programs with industry and with other partners. ALIS is again heavily involved in readying this information for computer-retrieval to facilitate marketing of new technology by AOSTRA.

In many ways it can be said that the oil sands industry and ALIS grew up together. AOSTRA is proud of the contributions that our information facility has made, and continues to make, toward the intelligent exploitation of our oil sands and heavy oil resources for the benefit of the people of Alberta.



THE AMOUNT OF TECHNICAL INFORMATION THAT HAS BEEN GENERATED BY AND/OR THROUGH AOSTRA IN THE LAST FIFTEEN YEARS IS ENORMOUS. DETAILED RECORDS FROM HUNDREDS OF LABORATORY INVESTIGATIONS, AND MASSIVE AMOUNTS OF DATA FROM FIELD PROJECTS HAVE ALL BEEN FILED WITH AOSTRA.

In turn, AOSTRA has made the results available to others in the form of thousands of reports, journals, and books. In its effort to produce timely reports and books that were useful, informative, readable yet technically very accurate and visually pleasing, AOSTRA has ventured into the physical aspect of publishing. In the early days, material was simply typed and sent out to a printer for typesetting and printing, and the final product was not directly under AOSTRA's control. To improve this situation, AOSTRA acquired in 1987 the equipment to begin its own desktop publishing program. The first project undertaken was the publication of the proceedings of The Third UNITAR/UNDP International Conference on Heavy Crude and Tar Sands. An enormous hardcover volume of some 1600 pages was successfully produced and this set the standard for subsequent publications.

This was followed by the proceedings of The Fourth UNITAR/UNDP Conference. An attractive five-volume set

of hardcover books that constitute a veritable library of information on tar sands and heavy crude was produced.

AOSTRA has also published its Technical Publication Series which makes available, research results, analytical procedures, and engineering data on the properties and behaviour of Alberta's petroleum resources that may not otherwise be available to the public. AOSTRA has published six volumes in the series and they are as follows:

Series #1. *Syncrude analytical methods for oil sand and bitumen processing.*

Series #2. *The thermodynamic and transport properties of bitumens and heavy oils.*

Series #3. *Aquathermolysis – a synopsis of work on the chemical reaction between water (steam) and heavy oil sands during simulated steam stimulation.*

Series #4. *Oil sands composition and behaviour research.*

Series #5. *A review of analytical methods for bitumens and heavy oils.*

Series #6. *AOSTRA Technical Handbook on Oil Sands, Bitumens and Heavy Oils.*

Also published are a number of smaller papers and reports such as *The Greenhouse Effect and the Alberta Fossil Fuels Industry*. This very popular discussion paper, which has gone to third printing, represents a preliminary attempt to assess the effects on the Alberta fossil fuels industry if international action is taken to limit emissions of "greenhouse gases," and the measures that might be considered to minimize any negative impact on the provincial economy.

AOSTRA has also been involved in publishing books and reports from other countries. For example, a report by ROMPETROL GEOMIN was translated and published.

AOSTRA also undertook to translate and publish the proceedings of the China-Canada Heavy Oil Technology Symposium Proceedings in 1987.

AOSTRA publishes technical periodicals as well. The AOSTRA Journal of Research is a prestigious research journal of international stature which is published quarterly. It contains a wide variety of papers dealing with oil sands, heavy

oils, enhanced oil recovery, upgrading and refining of bitumens and heavy oils, and related investigations such as steam generation and minimization of environmental problems. The TARpaper is an informative pictorial booklet which is also published quarterly. It has a readership of over 3000. It features newsworthy items, and highlights events and people at the leading edge of tar sands and heavy oil research. It is a vehicle whereby readers are kept informed of happenings and events relating to the oil sands scene, through a calendar and bulletin board. It is distributed free of charge.

It can be seen from the foregoing that AOSTRA has gone to great pains to make technical information on our petroleum resources available to those who can benefit in their investigations by having this knowledge base at their disposal. This technical publishing program, together with our AOSTRA Library and Information Service, has greatly assisted scientists and engineers in their research programs within the broad field of AOSTRA's mandate.



ONE OF AOISTRA'S MAJOR ROLES, SINCE ITS FORMATION IN 1974, HAS BEEN TO ENCOURAGE RESEARCH INTO NEW METHODS FOR FULLY UTILIZING OUR RESOURCES IN BITUMEN AND HEAVY OILS, AND IN INCREASING THE YIELDS FROM OUR CONVENTIONAL OIL FIELDS. MANY HIGHLY CREATIVE PEOPLE HAVE WORKED ON THESE PROBLEMS OVER THE PAST FIFTEEN YEARS, AND THE NEW IDEAS THAT HAVE EMERGED REPRESENT INTELLECTUAL PROPERTY THAT MUST BE PROTECTED.

AOISTRA has sponsored a very wide range of research and development programs at universities, at research institutions, and in the field, within the broad scope of its mandate. There has resulted over 180 invention disclosures, from which 18 Canadian patents, 17 U.S.

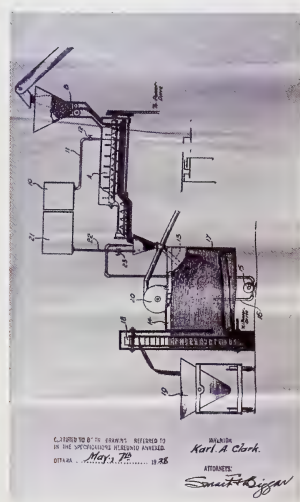
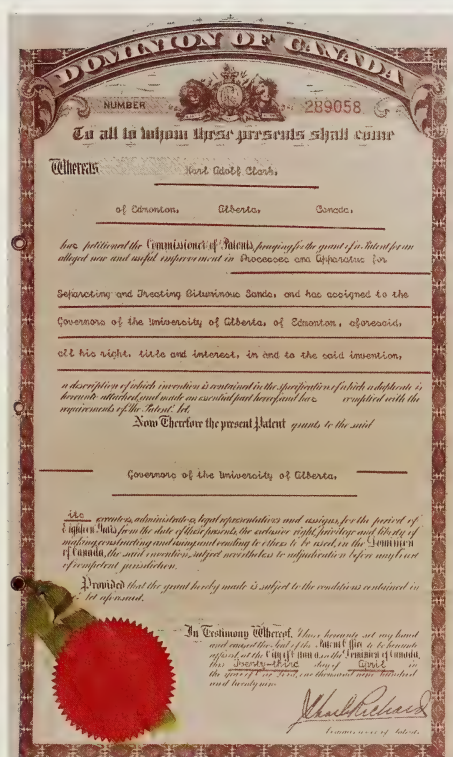
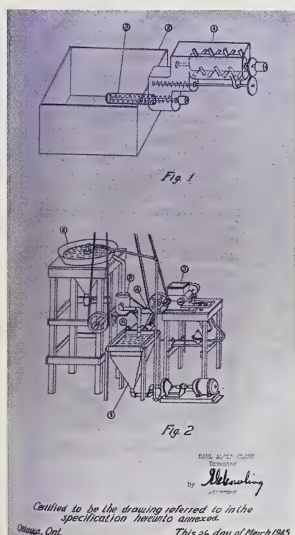
patents and 12 international patents have issued as of this writing. These patents range in content from new in situ thermal recovery processes to the use of ultramicro-sized bacteria for plugging permeable rock in

oil producing reservoirs. All of these creative innovations belong to AOISTRA and become part of our technology transfer activities in the course of developing new commercial opportunities for taking advantage of these new technologies.

The benefits from AOISTRA's activities as a sponsor of a broad spectrum of long-range research have been many, and important. This new research climate has led to a marked growth in postgraduate research opportunities in our universities, together with world-class research facilities

in our universities and research institutions. Our Province is now at the very forefront in research associated with AOISTRA's mandate. We have developed human resources fully capable of providing the new concepts from which will emerge the technical structures required for the oil sands mining, extraction, upgrading, and thermal recovery developments of the future.

Through our patenting system, our new technologies are protected, but at the same time they can be made available, at fair market value, to potential users throughout the world.



The beginning of an era in the extraction, separation, and treatment of bituminous sands with the issuance of a Canadian Patent to Karl Adolph Clark on April 23, 1929 with all rights assigned to the University of Alberta.

IT HAS BEEN POINTED OUT IN OTHER SECTIONS OF THIS PORTFOLIO THAT ALBERTA HAS ONE OF THE LARGEST DEPOSITS OF BITUMEN IN THE WORLD, TOGETHER WITH MAJOR RESERVES IN HEAVY OILS. HOWEVER, SUCH DEPOSITS ARE BY NO MEANS UNIQUE TO ALBERTA. IN FACT, HEAVY OILS AND OIL SANDS ARE TO BE FOUND IN OVER 16 COUNTRIES, WITH LARGE DEPOSITS IN VENEZUELA, THE SOVIET UNION, CHINA, AND THE USA.



AOSTRA representative Dr. David Redford discusses a point with a Pakistani field engineer at the Chak Naurang Oilfield in central Pakistan. This field produces 12°API oil from fractured carbonates at a depth of 2600 metres at reservoir temperatures of 94°C. The steam generator in the background is used to heat the oil on surface which is carried to steam heated production tanks through steam heated concentric tubing.

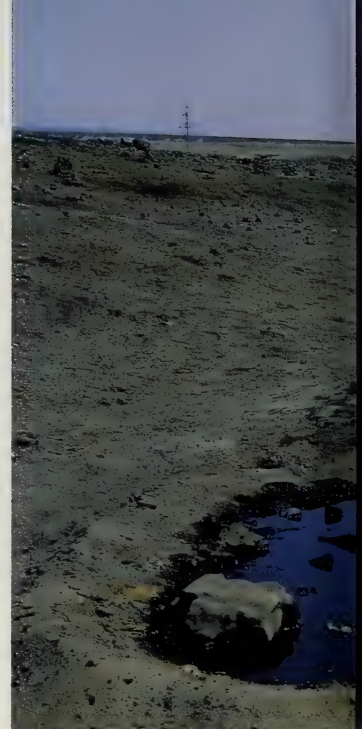
Through AOSTRA, Alberta has been at the very forefront in the development of the technology for the recovery and processing of bitumen and heavy oils. And in recent years AOSTRA has been very active in making this important technology available on a world-wide basis.

In addition to providing mechanisms for the sale of Alberta technology, goods, and technical services, these contacts with many countries throughout the world have enabled AOSTRA to bring back new foreign technology to Alberta. Indeed the benefits have been many including the fostering of good international cooperation and the assisting of developing countries to meet their energy needs.

The principal manner in which AOSTRA has developed effective working relations with foreign countries is through cooperative agreements designed to facilitate technology information exchange, the sale of goods and services, the training of techni-

cal personnel, and the organization of joint projects. Such agreements have been made by AOSTRA now with 17 countries. There has resulted many joint programs and projects, together with exchanges of technical information and assignments for specialized training. What is more, directly as a consequence of these agreements, and often indirectly through the personal relations that have developed, numerous sales of Alberta equipment and technology have been consummated.

An important example of how Alberta has benefitted from AOSTRA's activities in the international sphere concerns shaft and tunnel technology. One of the first commercial applications of this type of access drilling involved the underground heavy oils deposits at Yarega in the Soviet Union. Visits by AOSTRA staff to this site, followed by detailed studies and evaluations of the concept, including its adaptation to our Canadian reservoir conditions, led eventually to the establishment of our own underground shaft and tunnel access program, with the actual facilities located near Fort McMurray. This exciting new development for exploiting our Athabasca oil sands deposits is described in detail on page 48 of this Portfolio.



Heavy oils and bitumens, whether they be from Venezuela, Alberta, or the many other locations, world-wide, where they can be found, present certain common problems in converting them into lighter materials which behave more like conventional crude oils commonly processed in oil refineries. Here, AOSTRA has drawn heavily on the vast wealth of processing knowledge available in Germany, Japan, and the USA, as well as in Canada and Venezuela, to create new upgrading technologies specially suited for the efficient utilization of our immense resources in bitumens and heavy oils.

It is directly as a result of AOSTRA's international efforts that slant drilling rigs are now in operation in China, using Alberta technology, where it is leading to the preservation of valuable farmland. Furthermore, these efforts have led to the use of the AOSTRA-Taciuk Processor in the



United States and in India to clean up waste oil disposal sites. And in Australia this processor is now being used to recover oil from that country's rich deposits of oil shale. Our processor is also showing great promise as a means of recovering bitumen in Trinidad, and heavy oil in the Soviet Union.

Recently Hungary has successfully used in situ burning technology in light oil reservoirs to enhance recovery of the oil in place. AOSTRA, through relations with this country, is bringing this recovery technique to Alberta to determine if it has application in our light oil reservoirs.

Another major route that AOSTRA has taken to promote the international exchange of petroleum technology relating to heavy oils and tar sands involves cooperative ventures with such organizations as the United Nations Institute for Training and Research (UNITAR), the United Nations Development

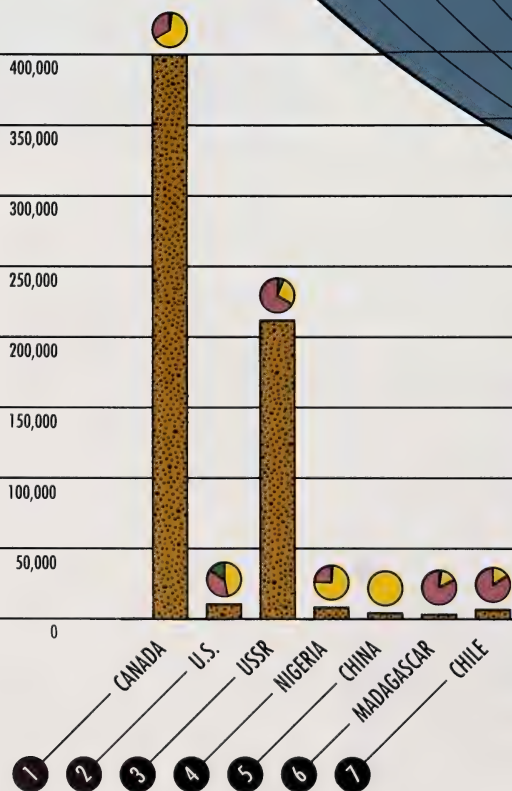
Program, Petro-Canada, the United States Department of Energy, and Petróleos de Venezuela. In cooperation with the aforementioned groups, AOSTRA has sponsored four international conferences on heavy crude and tar sands. Two of these international conferences were held in Alberta, while one each was held in Venezuela and the USA. In addition, together with these same organizations, AOSTRA has, since 1979, sponsored an information centre in New York relating to oil sands and heavy oils.

In summary, AOSTRA, through its very active international program, has been able to promote Alberta technology, in the area of its mandate, on a world-wide scale, while opening up international opportunities for Alberta entrepreneurs in the sales of goods and services. In addition, the very active two-way exchange of technical information that has taken place with other countries, has enriched Alberta's technical resources for recovering and processing its huge hydrocarbon holdings in heavy oils and bitumens.

TOP LEFT: In Karamay Oilfield in Northwest China (Xinjiang province), oil bubbles up in the desert sand, trapping blowing sand particles and forming a modern oil sand. The site is aptly called "Black Oil Mountain." ABOVE: Dr. Juan Chacín, President, Petróleos de Venezuela (PDVSA) and Mr. William J. Yurko, Chairman and Chief Executive Officer, AOSTRA, sign a six year Memorandum of Cooperation. Looking on is Dr. Neil Webber, Minister of Energy, Province of Alberta, and Mr. Manuel Ramos, Director, PDVSA. BOTTOM LEFT: AOSTRA representative James Yurko with field staff at one of the wet combustion production units at the Noorlatskoe field in Tataria, USSR. Tataria contains over 80 deposits of bitumen with in-place resources of 7 billion tonnes. Methods being tested in the area are wet combustion, injection of steam zone or bank with following water drive, cyclic steam stimulations, steam-gas injection, and low temperature oxidation.

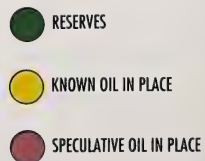


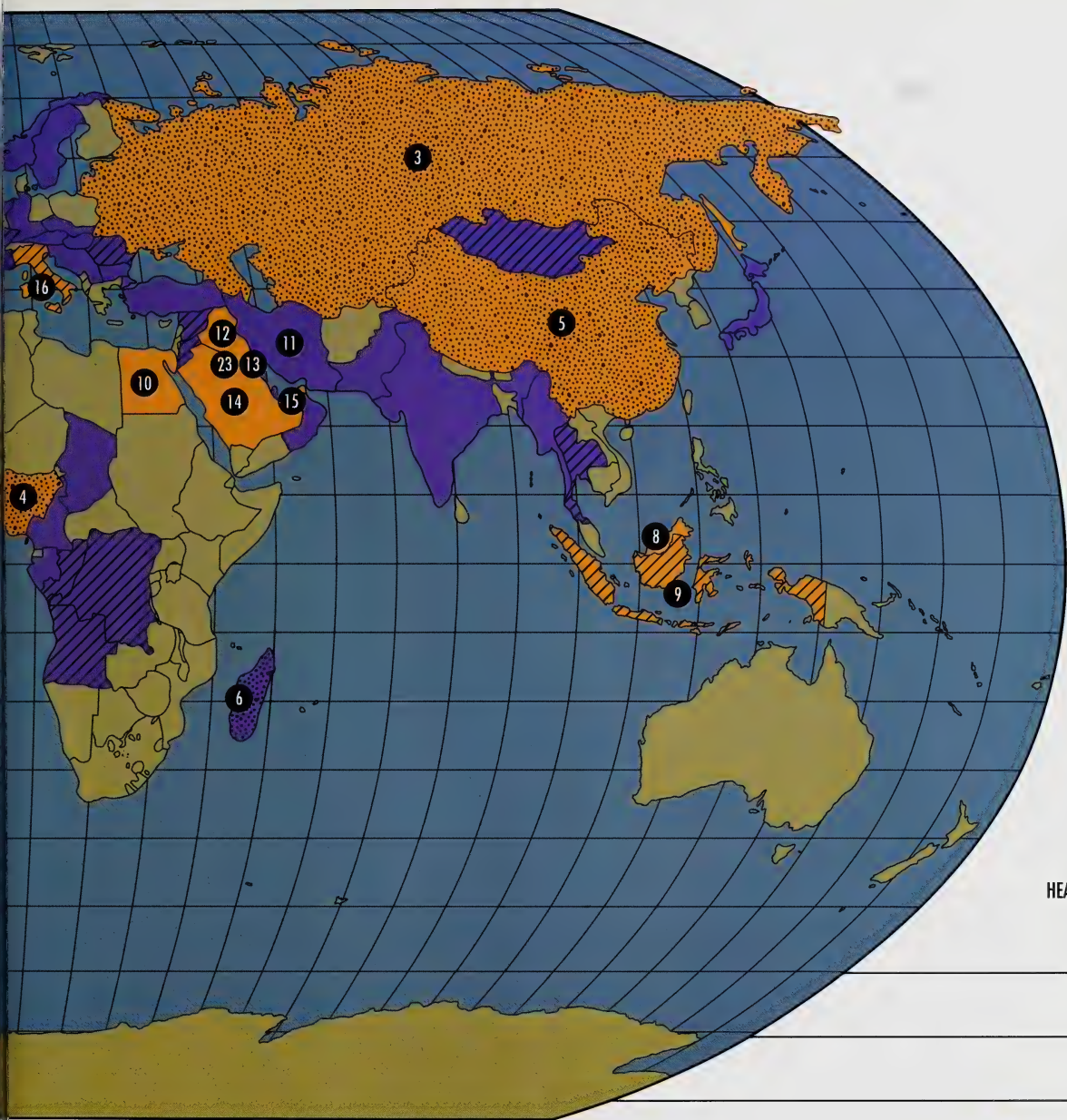
OIL SANDS ($\times 10^6 \text{ m}^3$)



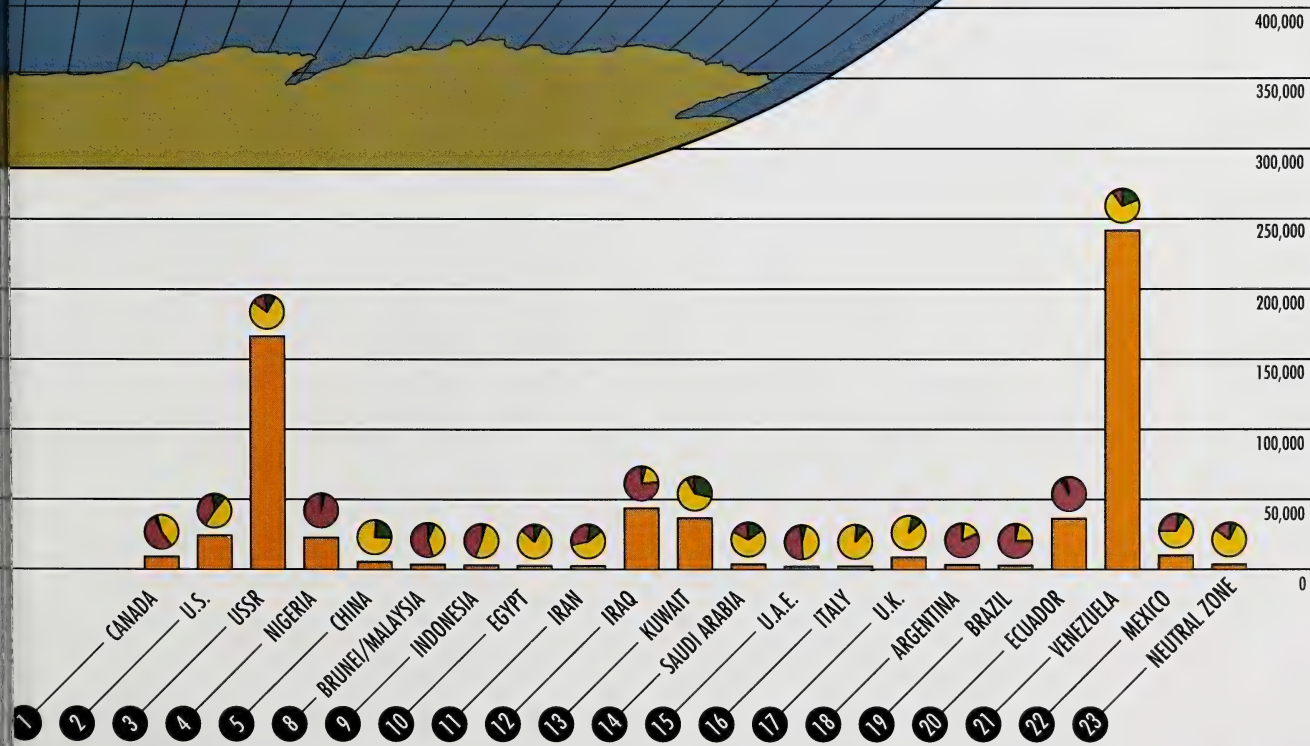
COUNTRIES WITH WHICH AOSTRA HAS MEMORANDA OF UNDERSTANDING:

ARGENTINA	JAPAN	TRINIDAD & TOBAGO
BRAZIL	MADAGASCAR	USA
CHINA	NORWAY	USSR
CUBA	PERU	VENEZUELA
CZECHOSLOVAKIA	ROMANIA	YUGOSLAVIA
HUNGARY	TURKEY	





HEAVY OIL (X 10⁶ m³)



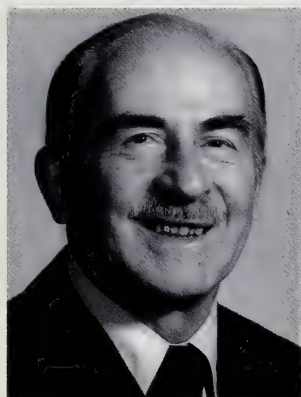


THE ACHIEVERS



IN RECOGNITION OF THE OUTSTANDING ADVANCES MADE BY THE LATE DR. KARL A. CLARK TOWARD THE COMMERCIAL DEVELOPMENT OF THE OIL SANDS, THE KARL A. CLARK DISTINGUISHED SERVICE AWARD WAS ORIGINATED BY THE CANADIAN SOCIETY FOR CHEMICAL ENGINEERING IN 1969. AOSTRA CHOSE TO ASSUME THE SPONSORSHIP OF THIS IMPORTANT AWARD IN 1982.

The Award is given to individuals who have made critically important contributions to the overall realization of the commercial potential of Alberta's oil sands resources. Clearly, it has taken many types of dedicated people to surmount the technical, economic, and social barriers facing those who seek the full utilization of these vital resources for the benefit of all Canadians. Therefore, potential candidates for the Award could justifiably come from every walk of life, and their contributions could be technical, commercial, or social in nature.



Nominations for this Award are received by AOSTRA and a panel of distinguished Canadians are chosen to select a suitable candidate for this important recognition. The consideration of candidates for the Award is made by April 1 each year. The Award will only be made when, in the opinion of the Panel, a truly appropriate candidate has been found.

This prestigious award was presented in 1969 to Mr. Sidney C. Ells; in 1982, to Dr. Paul E. Gishler; and most recently in 1989 to Dr. Clem W. Bowman.



*Award recipients:
above, Mr. Sidney
C. Ells (1969), far
left, Dr. Paul E.
Gishler (1982) and
left, Dr. Clem W.
Bowman (1989).
Opposite Page: Dr.
Karl A. Clark*



ABOVE: E.J. (Ernie) Wiggins, acting vice chairman of AOSTRA, has served as an AOSTRA Member since 1977. Before joining AOSTRA, Dr. Wiggins was director of the Alberta Research Council. RIGHT: Jacqueline Alton (seated), is executive assistant to AOSTRA chairman William Yurko. She also coordinates public relations efforts and is editor of the TARPaper newsletter. With Jackie are executive offices secretary and sixth-floor receptionist, Cindy Boissonnault (left) and Patricia Hunter, administrative assistant.

EXECUTIVE

RIGHT: William J. Yurko, Chairman and Chief Executive Officer, former member Alberta Legislature and Parliament of Canada.



RIGHT: Chief financial officer Walter Kowaluk's responsibilities include coordinating the budgeting process and managing AOSTRA's day-to-day financial affairs. FAR RIGHT: Financial clerk Melody Durand (seated), and accountant Karen Chizawsky.



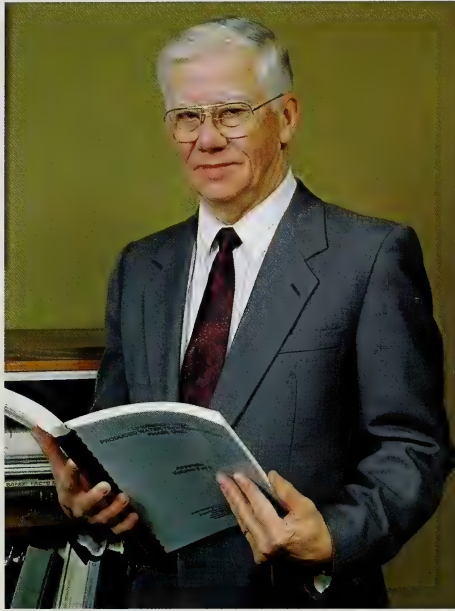
ABOVE: General Counsel Elma Spady provides vital legal services for AOSTRA, augmented by some 17 years of experience in the fields of resource exploitation and technology development. She and legal counsel Piyush (Peter) Mittal help to organize and legally formalize the many cooperative arrangements in which AOSTRA takes part.



RIGHT: George Villett, AOSTRA registrar, ensures that incoming proposals for AOSTRA support of R&D are complete, well documented and appropriately routed. He takes the official minutes of meetings of AOSTRA members, and also serves as personnel officer. LEFT: Administrative accountant Larry Miskiw with receptionist and switchboard operator Chelsi Eslinger (seated) and records coordinator Eileen Antoshkiw, in AOSTRA's fifth-floor reception area.



MINING, EXTRACTION & UPGRADING



L. Robert (Bob) Turner, pictured at left, is director of this arm of AOSTRA dedicated to improving technologies for oil sands mining, and bitumen extraction from mined oil sands as well as bitumen and heavy oil upgrading. Bob, shown here in his main office in Edmonton, may often be found in Calgary where his technical staff are located. BELOW: Shirley Lunde, also in Edmonton, is secretary to Mr. Turner.



ABOVE: Doug Komery, is manager of mining and extraction, and technology sales and commercialization. He and his staff are involved in the development and commercialization of technologies for the efficient mining of oil sands and the extraction of bitumen from mined oil sands. Doug also manages AOSTRA's projects related to preservation of the environment.



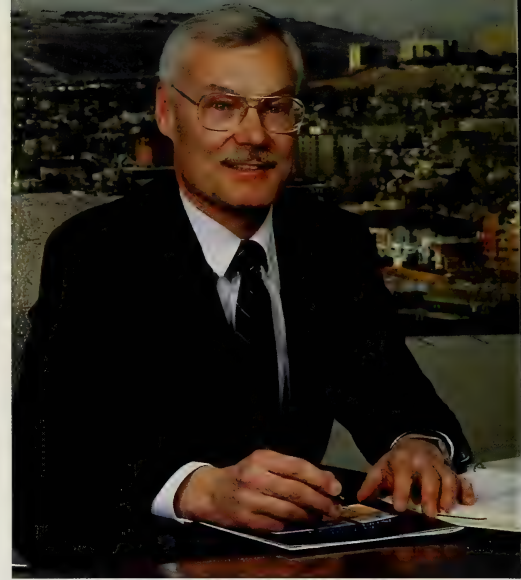
ABOVE: Roger Bailey, manager of upgrading projects, is responsible for evaluating novel upgrading processes and for arranging pilot- and commercial-scale tests of promising upgrading technologies in cooperation with AOSTRA's partners in the oil industry. RIGHT: Susan Emilsson provides word processing and other administrative support for the mining, extraction and upgrading group in Calgary.



ABOVE: Senior process engineer Riaz Padamsey (left) works with Roger Bailey and oil industry contacts to develop and evaluate upgrading processes. Senior engineers Roman Koszarycz (centre) and Richard Nelson work with Doug Komery in the areas of extraction and environmental protection, respectively.

IN SITU OPERATIONS,
TECHNOLOGY TRANSFER
& COMMERCIALIZATION

Richard Luhning, director of in situ operations, technology transfer and commercialization, has overall responsibility for AOSTRA's Calgary-based operations. His achievements since joining AOSTRA in 1976 include co-inventing AWACT, AOSTRA's patented anti-water-coning technology, and leading the development of AOSTRA's successful technology transfer program which has generated more that \$20 million in license revenues while putting state-of-the-art technology into the hands of industry.



ABOVE: Sharon Green manages and coordinates administrative support services vital to AOSTRA's Calgary operations, including information systems, records management and word processing. BELOW: On the job - word processor operators Connie Greany (left) and Beth Hill.



ABOVE: Shelagh Reimond (left), word processor operator and 15-year employee, with Kay Simpson who works in records management. BELOW: Eighteenth-floor receptionist Rita O'Leary with word processor operator Suzanne Van Elslande.





IN SITU OPERATIONS MANAGEMENT

John Scott, pictured below, is administrative manager for the various in situ projects in which AOSTRA participates. Working closely with AOSTRA's industry partners, he also serves on program management committees as Richard Lunning's alternate.



TECHNOLOGY TRANSFER AND COMMERCIALIZATION

Brad Anderson, works with other staff members and industry contacts to facilitate the transfer of AOSTRA-developed technology to industry. His marketing efforts help fulfill the goal of moving technological advances into commercial application.

Technical Representatives:

John Eubank (PanCan, BVI)
Slim Gennings (Dome, Shell)
Jim McKibbin (Norcen, Vikor)
Gus Van Der Voet (Husky)
Don Wright (AEC, Amoco)

COMPUTER SERVICES

Mike Carleton (below, centre), manager, and his staff provide computer services in support of simulation modelling and other technical applications, as well as for database management and the word processing network. Services include software support, equipment setup and maintenance, and trouble-shooting. BELOW: Systems supervisor Bob Curry (right) with systems analyst Craig Nelson.

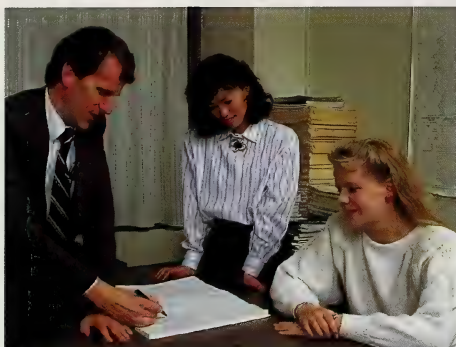
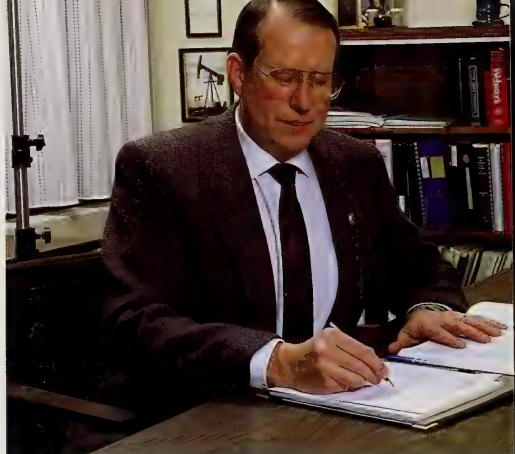


Systems analyst Rob Adachi (foreground) and programmers Jie Zhu (centre) and Barry Kreiser.



ENGINEERING & TECHNOLOGY DEVELOPMENT

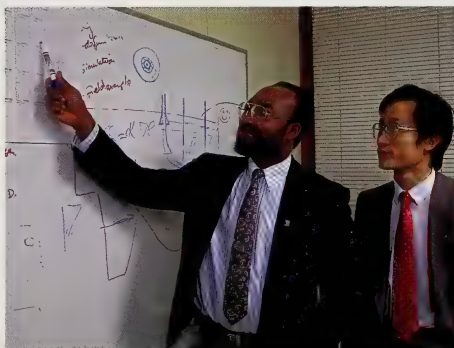
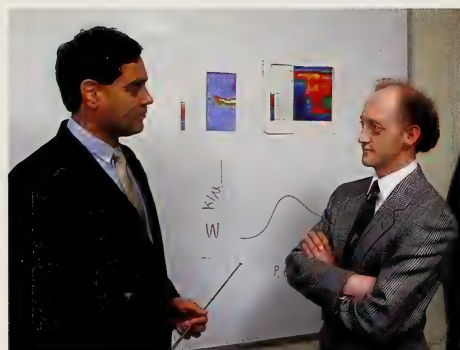
Manager, Bill Good (right), leads this group which analyzes and evaluates results from the numerous field projects in which AOSTRA participates. The objective is to develop improved technologies and find commercial applications for promising new ideas.



ABOVE: Principal reservoir engineer Ken Kisman, shown here with student engineer Josie Wu (left) and recent engineering graduate Denise Rechel, works to develop improved processes for in situ recovery.



Jack Suggett and his facilities engineering staff make sure that facilities and equipment for the numerous projects in which AOSTRA participates are of appropriate design and doing the required job. Here, Jack shows a damaged piece of equipment to engineering student Debbie Hamilton (left) and recent graduate Karen Gonie.



Reservoir engineers use computer models to assist in understanding recovery processes and to provide clues to process improvements. TOP LEFT: Senior reservoir engineer Gobi Kular (with pointer) discusses a thermal recovery project with student engineer Gerhardt Geib. ABOVE: Staff reservoir engineer Ben Nzekwu checks test results as student engineer Peter Yang looks on. BOTTOM LEFT: Senior reservoir engineer Sedat Gozde (standing) examines a numerical display with student George Yee.

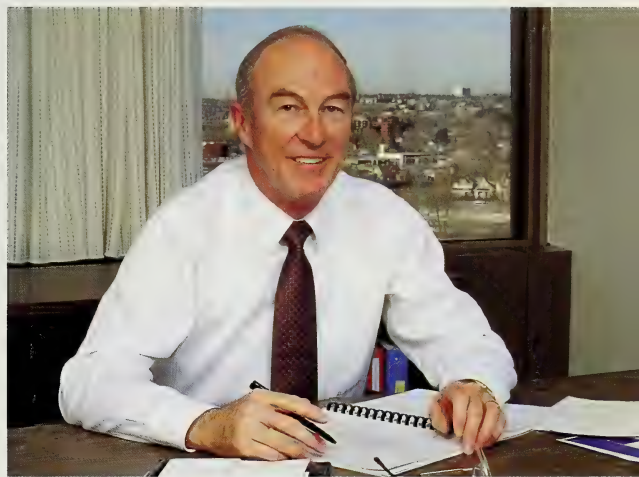


Facilities engineer Cody Wollen (left) and engineering graduate Nalin Joshi examine an item of equipment.

Senior geologist Jane Palfreyman works closely with reservoir engineers to ensure that recovery techniques employed are suited to reservoir geology. She is pictured below with student Brad Erick.



UNDERGROUND TEST FACILITIES



John A. (Jack) Haston, seen here in his Calgary office, is project manager for this large underground laboratory near Fort McMurray, where various in situ thermal recovery processes have been successfully tested under reservoir conditions.

RIGHT: Diana Dodyk provides word processing, reception, and other administrative support for the UTF program in Calgary. BELOW: Neil Edmunds (left) is process development coordinator for the UTF. His group is responsible for planning, analysis of field results and technical and economic evaluation. Neil is assisted by project engineer Garry McCarroll (right) and reservoir engineer Simon Gittins.



ABOVE: Site manager Cameron O'Rourke at the AO STRA-operated UTF. Looming in the background is the superstructure of the UTF's main elevator.

TECHNICAL PROGRAMS & INTERNATIONAL ACTIVITIES

David A. Redford, director of technical programs and international activities, leads AOSTRA's international projects, cooperative agreements and efforts in facilitating the exchange of scientific and technical information for the benefit of the tar sands and heavy oil industries in Alberta. He is also responsible for AOSTRA's program of research support involving universities and other institutions, and for the library and information services and publishing programs.

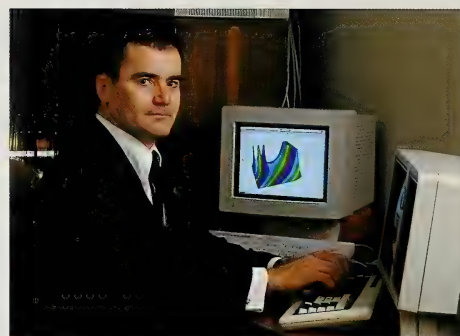


Philip Ross, manager of international programs and technology transfer, pursues opportunities for the international marketing of all of AOSTRA's technology. Phil is also responsible for all marketing of technology emerging from AOSTRA's institutional programs. In addition, he is engaged in the processing of patents and copyrights.

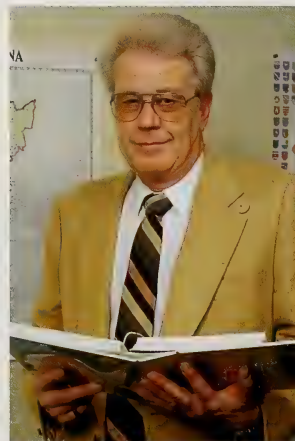
BELOW: Chu Hsi, manager of institutional programs, administers the program of financial support for research and is also involved in project evaluation and research planning.



RIGHT: Senior economist, Frank Werth assesses the economic potential of research proposals and evaluates ongoing projects from an economic point of view.



ABOVE: As manager of university research programs, Ted Cyr works closely with scientists at Alberta universities, promoting the exchange of information, evaluating results, and providing advice and required administrative support.



Diane Teppan (seated), manager of publications, with her assistant Rachel Recto (right) and Patty Hunt, secretary for Dr. Redford's group.



Dr. Harry Gunning has provided invaluable leadership and assistance in the preparation of this volume. His contribution reflects the insight and perspective acquired during his long and distinguished career.



BELOW: ALIS in Edmonton, front row, from left: Anna Kaplanski, information specialist; May Fallis, information clerk; Kelly Furtak and Rosa Tsen, database administrators. Back row, from left: Gene Lau, technical information officer; Trudy MacKenzie, administrative assistant; Helga Petri; Dagmar Losert and James Li, technical information officers; Marta Bor, assistant database administrator.



LIBRARY AND INFORMATION SERVICES

Helga Petri (left), is manager of AOSTRA library and information services (ALIS), which has outlets in both Edmonton and Calgary. ALIS distributes AOSTRA publications and maintains an extensive collection of scientific journals and other publications related to oil sands and heavy oils. In addition, ALIS has access to items from numerous other collections. BELOW: ALIS in Calgary - With Helga Petri, from left: Brenda Belland, information clerk; Gary Whitehead and Aleksandra Bizon, technical information officers; Marjorie Knive, Calgary office coordinator.



PORTFOLIO CONTRIBUTORS

Messages from:

The Hon. Don R. Getty, The Hon. Rick Orman, and Mr. William J. Yurko

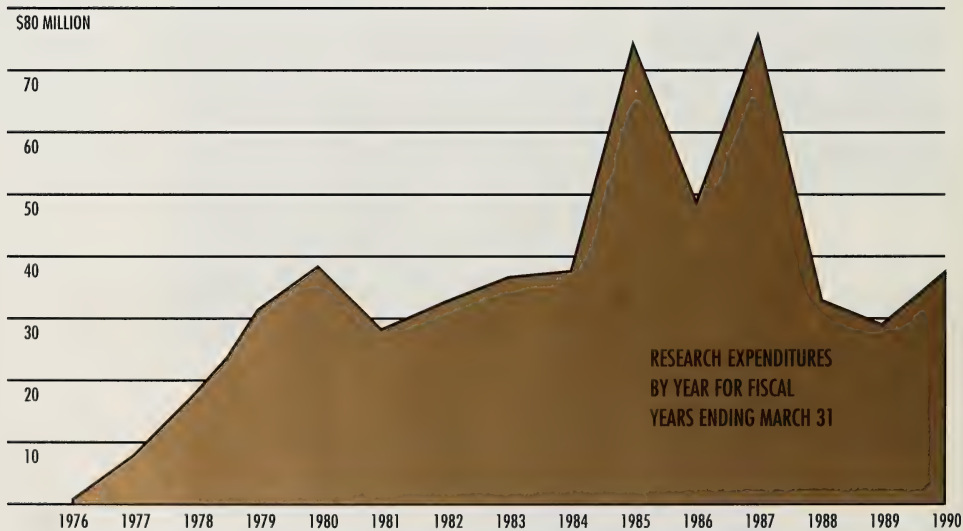
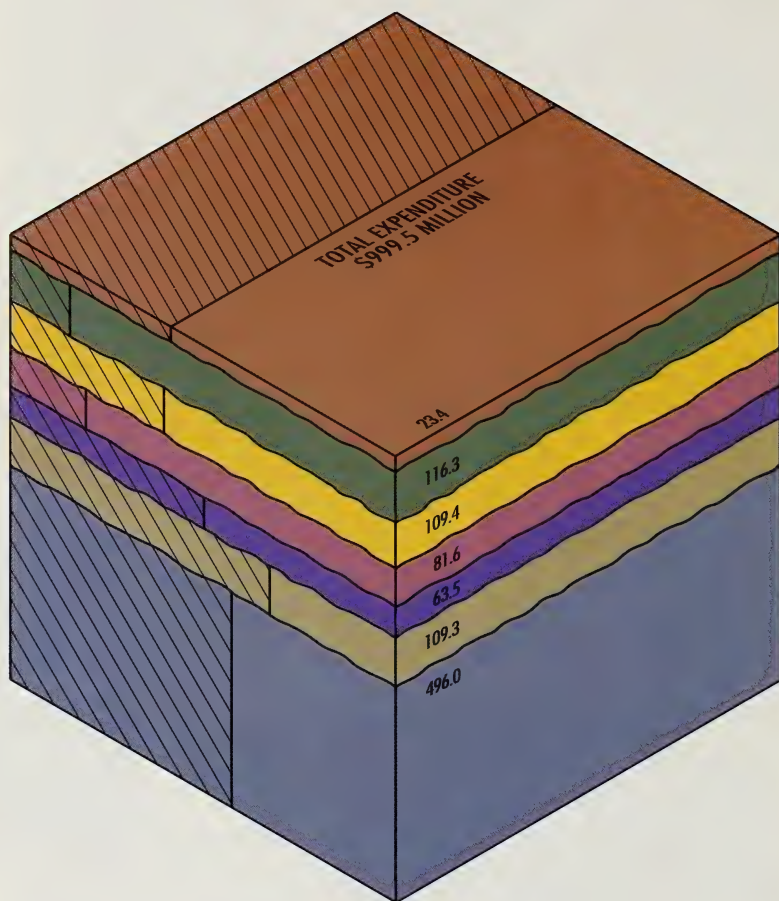
Section Authors:

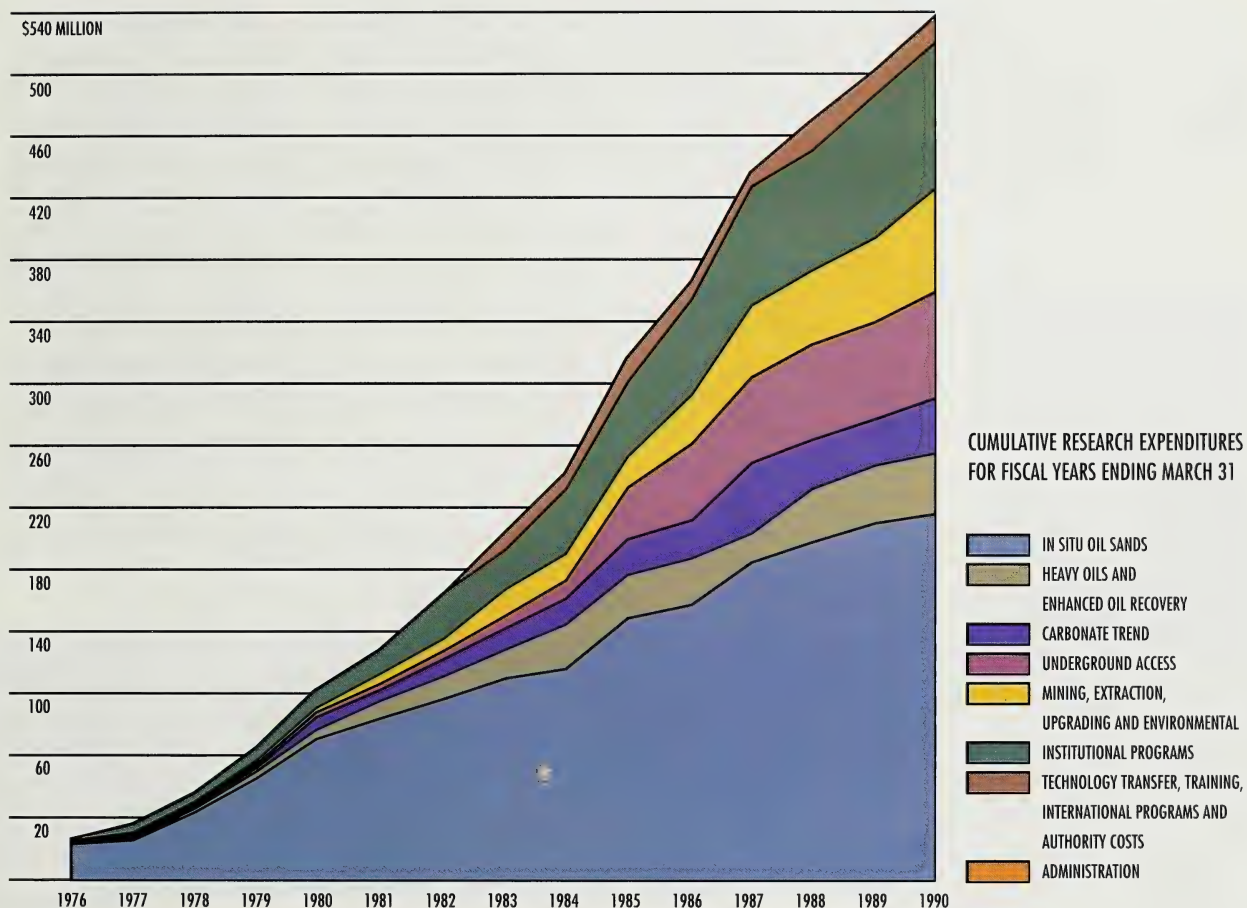
Jacqueline Alton, Roger Bailey, Ted Cyr, William Good, Harry Gunning, Jack Haston, Chu Hsi, Roman Kosarycz, Walter Kowaluk, Richard Luhning, Richard Nelson, Helga Petri, David Redford, Philip Ross, John Scott, Elma Spady, Diane Teppan, Robert Turner, and Ernie Wiggins

Other Contributors:

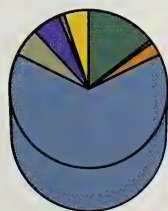
Studio 3 Graphics Ltd., James Sew Photography, Conrad Geitz, and Rachel Recto

CUMULATIVE EXPENDITURES BY
INDUSTRY AND AOSTRA ON
SHARED-COST ACTIVITIES 1976-1990





1976-1980
\$104.1 MILLION



1981-1985
\$224.8 MILLION



1986-1990
\$243.0 MILLION



CUMULATIVE EXPENDITURES
BY 5-YEAR INCREMENTS

IN THE PAST 15 YEARS, AOSTRA HAS INVESTED APPROXIMATELY ONE-HALF BILLION DOLLARS IN RESEARCH AND TECHNOLOGY DEVELOPMENT RELATED TO OIL SANDS, BITUMENS, HEAVY OILS, AND THE ENHANCED RECOVERY OF CONVENTIONAL OIL RESOURCES.



Elma Spady has been General Counsel to the Authority since 1977. She provides legal services to the Authority, including the formulation of all agreements in which AOSTRA is involved.

The mechanisms implementing this investment are in the form of a series of programs involving grants, effecting contracts, agreements and other forms of legal arrangements. A number in excess of one thousand of such arrangements have been concluded during this fifteen-year period.

AOSTRA/INTERNATIONAL PROGRAM

The AOSTRA/international program was announced at the first UNITAR (United Nations Institute for Training and Research) Conference on heavy oils and bitumen in June 1979. This program was intended to encourage cooperation between AOSTRA and government agencies from other countries in the funding of joint projects, exchanges of information, technical assistance, and staff training.

To accomplish these objectives, AOSTRA has concluded a written arrangement in the form of a "Memorandum of Understanding" with various governments including the United States, the USSR, the People's Republic of China, and several countries in South

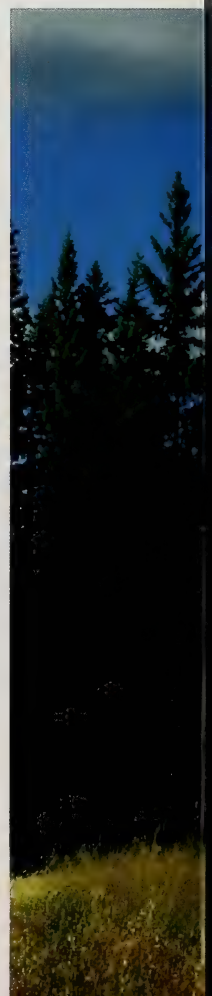
America and Europe. As these "Memoranda" are not in themselves legally enforceable documents, legal agreements providing for specific research projects with government agencies have been a necessary outgrowth.

AOSTRA/INDUSTRY PROGRAMS

AOSTRA's position in the industrial sector is to encourage individual and corporate inventors to direct their efforts towards specific problems. AOSTRA examines applications and funds those which are unique and, hopefully, of commercial value. AOSTRA owns the resulting information and keeps it confidential. New technology is made available to third parties at fair market value. Technology is normally made accessible to the industry partner and its affiliates on a royalty-free basis. Participation on a joint financial basis with industry ensures that technology is controlled by a central agency, but is available to others who desire to use it, thereby avoiding duplication among industry competitors. AOSTRA places a value on technology in an attempt to ensure that the goal of equivalent value for money invested in technological development is acknowledged.

AOSTRA/industry agreements include many of the following requisites:

- AOSTRA generally contributes 50% of project funding and has 50% of management control.
- AOSTRA obtains patents and generally owns all new technology.
- AOSTRA is the exclusive licensor in Canada for new technology.
- AOSTRA and the company can jointly or individually license outside Canada.



■ Licensing income is shared in proportion to financial contribution.

■ AOSTRA licenses third parties at a fair market value fee established by agreement with the participating company, or failing that, by arbitration.

■ AOSTRA may include a company's prior technology as required to complete its licensing package, with recognition of that company's expenditures for the prior technology in distributing the licensing income.

■ AOSTRA, Alberta Government agencies, the various industrial parties to the agreement, and their affiliates, may use project technology without payment of licensing fees.

■ AOSTRA may place its technical representatives in the company's office at project expense to acquire technology and assemble it in the form necessary for licensing.

■ AOSTRA and the company generally own all the project's physical assets on a joint basis and share all reve-

nue from their disposition and also receive proceeds from the sale of products.

■ AOSTRA requires repayment of its investment in a project on a time-value of money basis.

AOSTRA also provides funding to individual inventors in the form of grants or in closely-directed research agreements and may assist the inventor in finding a research facility to test the concept involved. It may ascribe a deemed value to the invention

to allow the inventor to share in the rewards arising from the application of his invention in future commercial ventures. Where AOSTRA provides funding in excess of the deemed value of the original invention, AOSTRA may require assignment of the invention to itself, and the inventor will receive a percentage royalty from future licensing based on a mutually accepted revenue-sharing formula.





AOSTRA/INSTITUTIONAL PROGRAMS

AOSTRA/institutional agreements provide for funding programs of various percentage interests but usually at the 100% level with AOSTRA owning the technology generated and having exclusive licensing rights on a worldwide basis. In order to foster a climate in which experienced and knowledgeable researchers will be able to participate on an ongoing basis in the development of hydrocarbon resources, AOSTRA has initiated "access" programs with industry participants wherein companies make a specified payment to AOSTRA annually to gain access to all technical reports generated from university projects and Alberta Research Council projects, along with the right to use the results of this research and to participate in decision-making respecting project direction.

AOSTRA's approach to entering research agreements with universities involves an attempt to meet the differing needs of AOSTRA, industry, and the universities themselves. Thus, the universities desire freedom to choose the subject of investigation, minimal restrictions on publication and dissemination of data, the ability to submit research results for advanced degrees as graduate students, and guaranteed funding as a residual benefit to the university. Access members, on the other hand, seek relevant research results, protection of company proprietary data, unrestricted user rights to new technology, availability of researchers during a project, timely reporting of results, and advance publishing access to data. And finally AOSTRA requires ownership of the technology, regular reporting of progress and results to industrial users, reasonable costs, relevance to AOSTRA's

mandate, and generation of solutions to existing industry problems. AOSTRA has successfully developed agreements which meet the diverse needs of the universities, the user industries, and AOSTRA itself.

MARKETING TECHNOLOGY

AOSTRA's licensing agreements reflect a policy of disseminating publicly-funded technology at fair market value and of sharing the revenues received with the inventor or developer based on the respective contributions to a research project. In order to maintain the intrinsic value of the technology, a reasonable rate of return must be obtained. AOSTRA attempts to emphasize the protection of the public interest in publicly-funded research, the proprietary rights of itself and others, and at the same time maintain its commitment to make technology available to the petroleum industry.

With regard to joint AOSTRA/industry projects, whether these are in situ field projects or extraction and upgrading projects, AOSTRA has employed a number of strate-

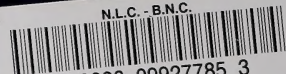
gies in marketing technology. The first of such methods is marketing prior to the completion of a project wherein interested third parties may obtain access to on-going technology by becoming a "consultive participant" in the project. In this case, the participant pays a small percentage of the total cost of the project without taking an active part in its management but nonetheless gains commercial use rights to the technology. The participant will lack any rights to revenues from production or licensing. The second method of marketing is the sale of the technology package following the completion of a project, wherein AOSTRA establishes a license fee based on the fair market value of the technology as a whole.

From the foregoing, it can be seen that the full implementation of AOSTRA's mandate has involved breaking new ground, in many instances, in the field of legal agreements, and other instruments of cooperation.





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